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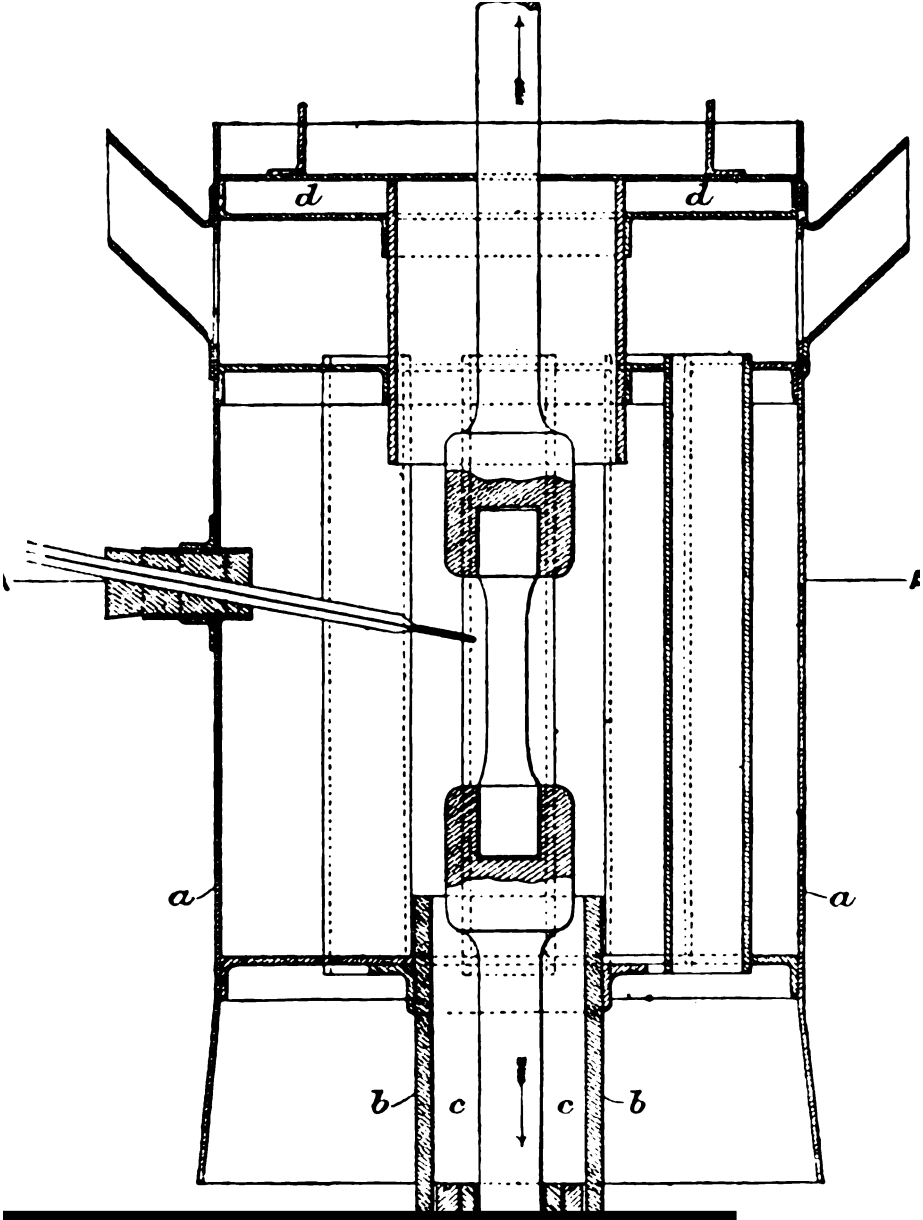

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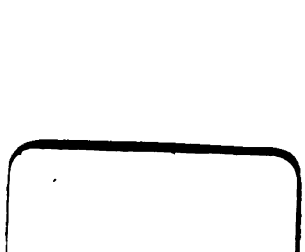

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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CL.

EDITED BY

J. H. T. TUDSBERY, D.Sc., M. INST. C.E., SECRETARY.

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CORRIGENDA.

Vol. cxlix. p. 99. Since this discussion took place Major Cardew has heard from Mr. Kapp that he has not abandoned the patent referred to, which differs in some important respects from the system proposed by Major Cardew.

,, ,, p. 145, l. 9, *before* "system" *insert* "Ward Leonard."

,, ,, ,, l. 11, *delete* "Ward Leonard."

,, cl. p. 324, last line of Table, 3rd column, *for* "0·9931706" *read* "0·9931508."

,, ,, p. 387, l. 16, *after* "All drifting sands tend to move" *insert* "in ridges or waves, which lie."

,, ,, p. 503, l. 28, *for* "corubin" *read* "coruby."

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THE
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SESSION 1901–1902.—PART IV.

SECT. I.—MINUTES OF PROCEEDINGS.

25 March, 1902.
CHARLES HAWKSLEY, President,
in the Chair.

(*Paper No. 3312.*)

"The Greenwich Footway Tunnel."

By WILLIAM CHARLES COPPERTHWAITE, M. Inst. C.E.

THE work described in this Paper is the second tunnel undertaken by the London County Council with a view to improve the means of communication between the districts lying north and south of the River Thames and east of the Tower Bridge. It is intended especially to connect the working-class district of the Isle of Dogs, where house-accommodation is scarce, with the areas covered by workmen's dwellings on the south side of the river.

A ferry between Greenwich and the Isle of Dogs has existed for a considerable period. The exclusive privilege of working it, which had been enjoyed since 1676 by a company called the Potter's Ferry Society, was partly abrogated by an Act of Parliament[1] passed in 1812, creating a statutory ferry for horses and vehicles, but leaving to the society its rights in respect to foot-passengers. The horse-ferry was extinguished by the Metropolitan Board of Works in 1883. The foot-passenger ferry-rights still exist, and are owned by the Great Eastern Railway Company and leased by them to the Thames Steamboat Company. Notwithstanding the grave objections and hindrances to a steamboat-ferry in a crowded river like the Thames, the yearly traffic amounts to about 1,300,000 passengers. In 1897 the London County Council obtained an Act of Parliament for the construction of a subway between Greenwich and Millwall, power being taken at the same time to compensate existing interests. The contract for the works was let to Messrs. J. Cochrane & Sons in March, 1899, and actual work was commenced in June of the same year. The shafts were sunk and the tunnel was bored by June, 1901, and the subsidiary works are now approaching completion.

[1] "Poplar and Greenwich Ferry Act."

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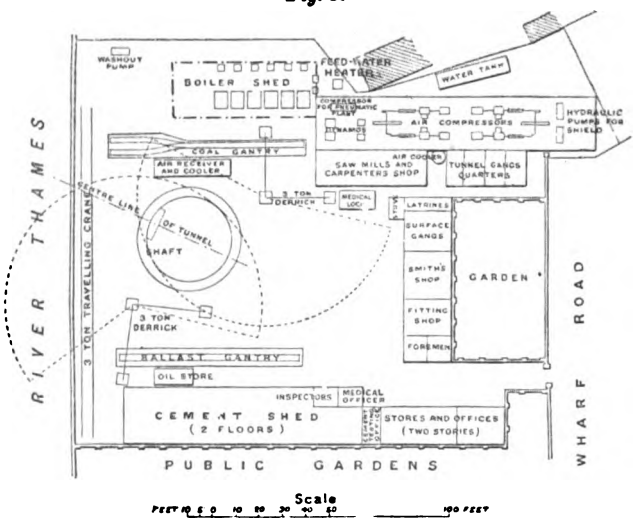
General Description of the Works.

The subway consists of a tunnel under the River Thames, connecting two shafts 1,217 feet apart; one situated in the Island Gardens, Poplar, in the Isle of Dogs, and the other on the west side of Church Street, Greenwich, and immediately behind the well-known Ship Inn. These shafts are 43 feet in external diameter, and within them are placed circular staircases and lifts to give access to the tunnel. Their depths from ground-level to the floor at the tunnel-entrance are respectively 44 feet and 50 feet. The external diameter of the tunnel is 12 feet 9 inches; it is of cast iron, and similar in character to other iron tunnels recently

Fig. 3.



Plan of Contractors' Yard, Poplar.

built in London. From each shaft the tunnel dips towards the centre of the river with a gradient of 1 in 15; the middle portion of the tunnel is on a gradient of 1 in 277, falling towards the Greenwich shore. These gradients were entailed by the advisability, from motives of economy, of limiting the depths of the shafts, and by the necessity of complying with the conditions of the Act authorizing the undertaking, which stipulated that the level of the tunnel should be such as to allow of dredging in the river a channel 500 feet wide and 48 feet deep at high water. The general plan and longitudinal section of the tunnel are shown in Figs. 1 and 2, Plate 1.

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It was arranged to drive the tunnel from the Poplar shaft; and a site for the contractors' yard, etc., was provided by enclosing temporarily a portion of the Island Gardens. The whole area available for the buildings and plant, including the site of the Poplar shaft, measured only 200 feet by 170 feet; and considerable ingenuity was shown by the contractors in utilizing the ground so as to provide for their machinery and at the same time for cement-stores and for the accommodation of workmen and others, as required by the contract. *Fig. 3* shows the general arrangement of the Poplar yard.

Shafts.

The two shafts are alike in general construction, and differ only in depth, that on the Poplar shore measuring 60 feet 4 inches from top to cutting edge, and the Greenwich shaft 66 feet 8 inches.

Caissons.—The caissons are 35 feet in internal, and 43 feet in external diameter, and are formed with two steel skins, the 4-foot space between which is filled with 6 to 1 Portland-cement concrete. The skins are formed of horizontal rings built up of plates, which are generally about 4 feet 9 inches in depth and vary in thickness from $\frac{5}{8}$ inch at the bottom of the caisson to $\frac{5}{16}$ inch at the top; the vertical joints in each ring are arranged, wherever possible, to break joint with the rings above and below. The skins are braced together with vertical angle-bar frames and horizontal angle-bracings. At the points where the main girders of the air-tight floors are attached, the webs of which are carried through to the outer skin, vertical plate gussets are fixed in the rings above and below, to resist deformation under the severe stress produced at the ends of the girders by the air-pressure on the floor. The stress in each flange at the wall of the caisson with a pressure of 20 lbs. per square inch amounts to nearly 300 tons. Around the tunnel-opening, also, the caisson is strengthened by numerous plate gussets.

The cutting edge is 7 feet in depth, and is formed by inclining the inner skin to meet the outer: at the edge thus formed an extra plate, $\frac{3}{4}$ inch thick, is placed round the outer skin for greater stiffness. The bottom edges of the cutting-edge plates are not flush with one another, but each edge is 1 inch above that of the plate outside it, so as to allow of easy caulking. The cutting edge is further strengthened by forty-eight triangular vertical gussets $\frac{1}{2}$ inch thick. At the top of the inside skin of the cutting edge is fixed round the entire circumference an angle-bar 6 inches by 6 inches by $\frac{3}{4}$ inch. It was intended to use this as a bracket under

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which timbers could be fixed in order to control the sinking of the shaft. In practice, however, all such work was done by timbers fixed under the main girders of the air-tight floor.

The outer skin of the caisson was without the usual batter, but the plates of each ring were inclined outwards towards the top, so that the top edge of every ring touched a vertical cylinder. The caisson was therefore of uniform diameter from top to bottom, excepting for the extra $\frac{3}{4}$-inch plate at the cutting edge; and although the absolute necessity of preventing any spreading during the erection of the successive rings (whereby the caisson would have been made wider at the top than at the bottom) rendered great care necessary in riveting up the work, still the extra trouble and expense so incurred were more than compensated for by the results obtained in the sinking of the shafts: results which the Author believes were largely due to the absence of taper in the shafts and of consequent settling of the ground around them. Iron rivets were used throughout; and all riveting, whether gap-riveters or hand-pistols were used, was done by compressed-air power. Three tiers of pipes were fitted through the sides of the caisson, and connected to the wash-out pump, through which water could be pumped to lubricate the outer skin in case of necessity. These, however, were little used.

Air-tight Floors.—Each caisson is provided with two air-tight floors, a permanent one fixed below the tunnel-opening and above the cutting edge, and a provisional one fixed, when in use, a few feet above the tunnel-opening. These floors were alike in construction, being formed of two pairs of main girders crossing each other at right angles; the intermediate areas were crossed by small girders and the whole frame was covered by buckled floor-plates bolted to the girders. The provision of two air-tight floors has the advantage that, while a single floor above the tunnel-opening is a necessity for starting the tunnel-shield in water-bearing strata, the use of the lower floor only during the operation of sinking the caisson, while allowing an ample working-chamber underneath for the miners, enables any kentledge used in sinking to be placed near the bottom of the caisson, and so keeps the centre of gravity of the whole structure, when sinking, much lower than is possible with an upper floor only. This lessens materially the tendency of the shaft to tilt over to one side when sinking. Against this advantage must be set the increased cost of the shafts, due to the extra depth required to make room for a floor with girders 4 feet 6 inches in depth, clear of the tunnel-opening above it and the cutting edge below.

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Tunnel-Openings.—The opening in each shaft for the tunnel is 15 feet 3 inches in diameter. During the sinking of the caisson it was closed by a "plug" formed of steel plates, fitted between girders in such a way as to be removable singly when the shaft was sunk to its proper depth and the shield was ready to start. The face-plates of the "plug" were held in place by two girders, which divided the opening into three horizontal strips about 5 feet deep. These areas were again divided vertically by three smaller girders, 5 feet apart. The face-plates were fitted and bolted to the girders in the areas so formed, wood packings being used, to facilitate their removal when necessary. Bolts were also used for making up the girders, so that they could be removed in pieces. The girders were bolted to horizontal brackets, fixed on the skin of the circular plug-opening, and themselves removable.

Method of Erection and Sinking.—As the methods employed in sinking the two shafts were identical, it will suffice to describe the work on the Poplar shaft, which was the first one sunk. All the steelwork used in the caisson was first put together in the builders yard in sections of not less than four rings at a time, so as to ensure good fitting; and so well was this work supervised that, when it was put together again on the site of the shaft, but little adjustment was found necessary. To ensure the caisson being perfectly cylindrical, which was particularly important for the reason already mentioned, the contractors were required to put in the concrete filling between the skins as the erection of the steelwork advanced, that is to say, the concrete filling for each ring was (save in exceptional circumstances, such as frosty weather) always put in to within 2 feet of the top before the riveting of the next ring was proceeded with. It was therefore necessary to make each ring absolutely correct before going on with the next above, because, the concrete filling once in, no further adjustment was possible. Only in the two top rings, when all danger of the shaft being jammed in sinking had disappeared, was this procedure departed from. This method of working was also advantageous in ensuring that the concrete filling was tipped only a few feet from the skip. As soon as the cutting edge and the lower air-tight floor with the ring surrounding it were riveted up, and the concrete filling was in place, the blocks on which the caisson had stood were removed and the sinking was commenced; but for some time, owing to delays in the delivery of the steelwork, very slow progress was made.

The erection of the caisson was commenced on the 26th September, 1899, and by the 13th March, 1900, one-half was erected and the

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cutting edge was sunk to a depth of 24 feet 6 inches below ground-level, when the quantity of water met with prevented further progress, and sinking was stopped until the arrangements for working in compressed air could be completed. So far the sinking of the caisson had been done in the open, the material inside the shaft being removed in the ordinary way, and the lowering of the structure being controlled by foot-blocks under the cutting edge. No kentledge was required at this stage, the shaft going down easily when released, and being never more than a few inches out of level. The material passed through was mainly river-mud and silty clay; but at 22 feet below the surface ballast was found, through which, as already stated, water found its way from the river, the water in the caisson rising and falling with the tide. In order to continue the sinking of the caisson under compressed air the bottom floor-plates were fixed on the girders, and the upper floor-girders were erected in position. On these upper girders were placed the air-locks, from which shafts 3 feet 6 inches in diameter were carried down through the lower floor, thus giving access to the working-chamber below it (Fig. 4, Plate 1). On the 2nd May, 1900, the work of sinking the caisson was resumed under compressed air, the erection of the steelwork of the caisson having in the meantime been completed to within 15 feet of the total height. The remaining rings were erected during the time the shaft was sinking.

The method of sinking the caissons under compressed air was as follows. Starting usually with the ground-level in the pressure- or working-chamber about 1 foot 6 inches above the bottom of the cutting edge, the miners excavated daily to a depth of about 1 foot below it, leaving all round the cutting edge a berm between 1 foot and 2 feet in width. The amount of excavation was limited by the number of skips which could be passed through the vertical air-lock in a given time; and in practice it was found that four men working in the pressure-chamber could keep the skips filled as fast as they could be returned empty. Daily, generally during the breakfast-hour of the morning shift, when the men were out of the caisson, the air-pressure in the working-chamber was lowered until the caisson commenced to move. No further reduction of pressure was then made, and the movement of the caisson was gradually stopped by the tapered cutting edge burying itself anew to a depth of 1 foot to 2 feet below the general level of the excavation. The air-pressure was then again raised sufficiently to dry the bottom of the shaft, and the same process of excavating and sinking was repeated. It was found possible to carry on simultaneously the

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different operations of plating and riveting the skins, putting in the concrete filling, and sinking the shaft; and by careful organization it rarely happened that one operation interfered with or delayed another. It will be seen from the Table giving details of the sinking-operations (p. 8) that the daily progress under compressed air was singularly uniform.

The strata met with 3·00 feet below Ordnance datum, or about 20 feet below ground-level, were water-bearing. The top surface of the ballast, which was found on the north side of the caisson about 22 feet below ground-level, sloped rapidly southward, and some difficulty was expected in keeping the cutting edge level on that account. As a matter of fact, for a few days the error of level of the caisson amounted to 6½ inches, being the largest amount of tilt recorded; but this was put right, and subsequently the caisson, though sinking at an average rate of 1 foot 3 inches per day, was never more than 1¾ inch out of level. Below the ballast, at about 41 feet below ground-level, was found a bed of close grey sand, at times almost as tough as soft sandstone. It was noticed that the skin-friction of the caisson, which, when the lower portion was in the ballast, had been generally 4·5 cwt. to 4·7 cwt. per square foot, became less as the cutting edge sank deeper into the sand; and the last observations, taken when the caisson was nearly down to the required level, gave a skin-friction of just under 3·8 cwt. per square foot. The probable explanation is that, owing to the consistency of the sand, most of the air escaping from the pressure-chamber passed up close to the outside of the caisson and so made an air lubricant for it. The lubricating-pipes which were provided in the caisson were used on a few occasions, but without appreciable results, perhaps owing to the choking of the pipes by the dirty water used, but more probably owing to the air that escaped from below driving away the water from the caisson as soon as it left the pipes.

The total weight of kentledge put into the caisson was only 921 tons, which, with the weight of the steel and concrete in the structure, made finally a total weight of 2,560 tons. By the provision of an air-tight floor at the bottom of the shaft, the contractors were enabled to provide the necessary kentledge by tipping the ballast as it came up through the air-locks into the shaft below, and by running in water from a pipe above. As stated above, the sinking of the Poplar shaft under compressed air was commenced on the 2nd May, 1900. It was sunk to the required depth by the 31st of the same month. The Table shows the daily progress from the 10th May onward, with the loads

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on the caisson, pressure, etc., from the commencement of work under compressed air until the shaft was sunk to the required level.

Date.	Depth of Cutting Edge below Surface.	Cutting Edge out of Level.	Depth sunk each time of lowering.	Load on Shaft including Kentledge.	Air-Pressure.	Remarks.
1900. May.	Feet.	Inch.	Feet.	Tons.	Lbs. per Sq. Inch.	
2	24·80	½	..	1,346	6	Pressure put on. Cutting edge in ballast at north side.
7	27·50	6½	2·70	1,362	6	Skin-friction 4 cwt. per foot.
10	28·60	1⅜	1·10	1,412	6	
11	29·60	1¾	1·00	1,457	8	
12	31·83	⅞	2·23	1,618	8	
13	33·70	1¾	1·87	1,826	8	Skin-friction 4·7 cwt. per foot.
14	35·80	1⅛	2·10	1,943	8–10	
15	37·26	⅞	1·46	2,114	10	Skin-friction 4·75 cwt. per foot.
16	39·16	⅝	1·90	2,257	10–11	
17	39·96	⅝	0·80	2,371	11–12	
18	41·50	⅞	1·54	2,371	11–12	Cutting edge in close grey sand.
19	42·50	1	1·00	2,371	10–11	Skin-friction 4·6 cwt. per foot.
20	43·60	1	1·10	2,371	10	
21	44·75	½	1·15	2,421	10	
22	46·42	1⅝	1·67	2,421	10½–13	
23	48·31	⅞	1·89	2,421	11–13	Lubricating-pipes in use.
24	49·46	⅞	1·15	2,421	13	
25	49·82	¾	0·36	2,421	14	
26	51·80	⅜	1·98	2,449	15	
27	53·35	⅝	1·55	2,477	15½	
28	55·20	⅝	1·85	2,505	16	
29	57·13	⅝	1·93	2,533	16½	
30	58·55	½	1·42	2,561	16	
31	60·30	..	1·75	2,561	20	Skin-friction 3·8 cwt. per foot.

It will be seen from this Table that from the 10th to the 31st May, a period of 22 days, the depth sunk daily varied but little, only twice falling below 1 foot and twice exceeding 2 feet. When sunk to the proper depth the caisson was exactly plumb. As the Greenwich caisson was sunk in a similar manner, and with the same uniform speed and accuracy, the use of vertical sides to the caisson, and of an air-tight floor near to the cutting edge during sinking, would appear to be justified. The vertical sides of the caisson prevented, as far as could be seen, any disturbance of the surrounding ground during the operation of sinking; at least no cracks were visible on the surface more than two or three feet away, and those which appeared within that distance were slight. When the plug of the tunnel-opening was removed and the shield was pushed forward into the solid ground, no previous

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movement of the strata was perceptible. The steadiness of the caisson when in motion was no doubt due in part to the slight disturbance of the surrounding ground; but the lowness of the centre of gravity of the structure, due to placing the kentledge near the bottom of the shaft, probably also accounted largely for the ease with which it was controlled.

On the question of the batter of caissons some interesting remarks were made in the course of the discussion on the Blackwall Tunnel.[1]

Removal of Tunnel-Plug.—As soon as the Poplar shaft had been sunk to the required depth, the working-chamber under the air-tight floor was filled with 6 to 1 Portland-cement concrete to the level of the underside of the floor-girders; and when that had set, pressure was taken off, and the floor-plates were removed. Concrete was then filled in between the girders to just below the floor-level, and the plates were replaced, grout being afterwards forced beneath them under pressure, through holes provided for the purpose. The material for the shield was then lowered through the upper floor-girders, the air-locks and tubes being moved for the purpose, and the shield was erected on a timber cradle laid on the lower floor. The position of the shield during erection is shown by dotted lines in Fig. 5, Plate 1. A ring of concrete was then built inside the tunnel-hood, leaving an opening large enough to admit of the passage of the shield. Behind the shield some temporary tunnel-rings were built, extending to the skin of the caisson, for the shield to push against. This done, the upper floor-plates were fixed on the girders already in position, the air-locks were replaced, and air-pressure was again applied. The actual removal of the "plug" was carried out as follows (Fig. 5). Across the plug-opening, at a distance of 4 feet from the steel plug, and about 5 feet from the invert of the plug-opening, a 12-inch by 12-inch timber was fixed, bearing on the concrete ring previously referred to, which was itself secured by rails bolted to the circular hood. Below it was placed a 12-inch by 6-inch timber, similarly bearing against the concrete; and close poling was then built in front of the joists, forming a diaphragm from the invert of the plug-opening to above the level of the lower girder of the plug. The lower plates of the plug were then removed one by one, and the space between the solid ground so exposed and the timber diaphragm was filled with well-pugged clay. The lower girder was then removed, the

[1] Minutes of Proceedings Inst. C.E., vol. cxxx. pp. 80-89, *passim*.

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bottom edges of the plates above it being held by stretchers to the 12-inch by 12-inch timber. Two similar timbers were then fixed above the first, and close poling was placed in front of them, thus raising the timber diaphragm to the level of the second girder of the plug; the plates below were in turn removed, and the exposed face was supported by clay filling as before. In this way all the steel plug was removed, and in its place the tunnel-opening was closed by a timber diaphragm and some 4 feet of clay in front of it. The shield was pushed forward until it touched the timber diaphragm, which was subsequently cut out to allow of its passage.

Tunnel-Lining. (Figs. 6, 7 and 8, Plate 1.)

The cast-iron lining of the tunnel is similar in character to that used in previous works of the same kind. It is 12 feet 9 inches in external diameter and 11 feet 9 inches in internal diameter, the rings being 1 foot 8 inches long, and each consisting of eight segments and one key-piece. The weight of the lining is 4 tons 2½ cwt. per lineal yard: that of similar lining for tunnels in London clay is about 2 tons 17 cwt. per lineal yard. The bolt-holes in the circumferential flanges of the segments are arranged so that adjoining rings can be made to break joint, as was done throughout the tunnel. All bolt-holes were made with their outer edges bevelled off, as shown in Figs. 7 and 8, Plate 1. When the bolts were put in, lead washers (short lengths cut from lead piping) were put on them; and, on the bolts being screwed up, the lead completely filled the space around them at each end made by the bevelled edges of the bolt-holes. This arrangement proved very successful, and comparatively few bolts were found to be leaking when the air-pressure was removed. The risk of damage by electrolysis did not appear sufficiently probable to forbid the use of lead. All joints of castings were planed, except on the space left on each face for caulking. These spaces were filled with the usual mixture of iron filings and sal ammoniac; but before filling the mixture in, soft lead wire was everywhere hammered in. The regular use of this lead wire, which kept out the water while the rust-joint was hardening, resulted in considerable saving later; for when the air-pressure was removed there were less than a dozen places in the 12,000 lineal yards of caulked joint which required cutting out and recaulking. The grouting-appliances for filling in spaces behind the tunnel-lining were of the usual character.

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The Shield.

The shield employed in making the tunnel was of the kind known as the "trap" or "box" shield. The trap consists essentially of two diaphragms, the front one filling the upper half, and the back one the lower half, of the circle enclosed by the cylindrical skin of the shield. The bottom of the front diaphragm is a few inches lower than the top of the back one. In the event of an inrush of water from a "blow" occurring at the face, the water must flow over the top of the back diaphragm to get into the tunnel, and before it rises high enough to do this the bottom of the front diaphragm is under water, and all escape of air through the shield is stopped. The water in fact becomes a seal to hold the air.

Historical Notes on the Trap-Shield.—The first shield of this type actually used was employed in a tunnel under the Mersey, made in connection with the Liverpool Waterworks, and was briefly described in the discussion on the late Mr. J. H. Greathead's Paper on "The City and South London Railway."[1] In that Paper is figured[2] a shield with a combination of trap and air-lock, designed by Mr. Greathead, and actually constructed in 1876, for use in a projected tunnel under the Thames at Woolwich. The Author believes that, with these two exceptions, no communication dealing with this kind of shield is to be found in the publications of the Institution. The diagrams, *Figs. 9*, which show side by side successive shields built on the trap principle, may therefore be of interest.

It will be seen in Mr. Greathead's Woolwich shield that, combined with the trap formed by two diaphragms, there is an arrangement for placing the front of the shield under compressed air, the tunnel behind being apparently under normal pressure.

The Mersey shield was originally a shield with a concave diaphragm consisting of removable plates with a door at the bottom. This proved unsatisfactory, however, and the shield was modified under the advice of Sir Benjamin Baker, K.C.M.G., Past-President Inst. C.E., in 1891, as shown in *Figs. 9*, and gave good results. The lower half of the original diaphragm was replaced by shutters or curtain-plates. Farther back in the shield was built a box forming the back diaphragm of the trap. By means of a sliding lid to this box the whole face could be completely closed. The work of excavation was carried on by removing one or more of the

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. pp. 100 and 104.

[2] *Ibid*, p. 66.

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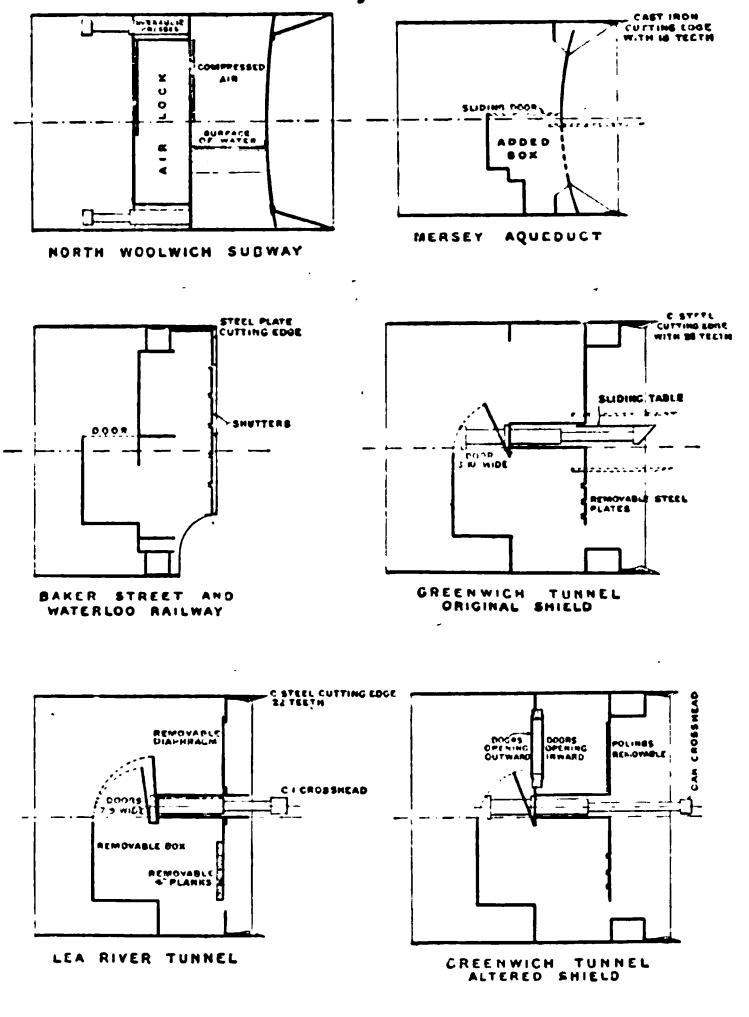
curtain-plates below the front diaphragm, and removing the face at the bottom, needles being driven forward into the solid about

Figs. 9.



EVOLUTION OF THE "TRAP" SHIELD.

half-way up the face to prevent too much spoil from coming down in front of and above the cutting edge. The teeth or knives on the

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cutting edge were a useful feature of the shield, and greatly lessened the amount of power required for pushing it through ballast. The experience gained with this shield, and the method of working adopted, suggested several features in the Greenwich shield as at first constructed.

A trap or box shield (*Figs. 9*) was used in the Baker Street and Waterloo Railway tunnels under the Thames at Charing Cross.[1]

In *Figs. 9* is also shown the arrangement of the shield used in the Greenwich Tunnel, before and after alteration. Essentially it is similar in design to the shield previously described for the Mersey aqueduct tunnel; but face-rams with sliding tables have been added, which with other details will be described later.

The remaining diagram in *Figs. 9* shows a shield now in use in a tunnel under three arms of the River Lea required in connection with some main-drainage extensions. The Author is assisting Sir Alexander Binnie in this work, and the shield was designed about the same time as the shield for the Greenwich Footway Tunnel, but before the latter work was commenced. In the Lea shield, which has the diaphragms common to the others, face-rams with square cross-heads are provided. The object is to work with a timbered face held up by these rams—which, when extended, project well beyond the cutting edge—and then, as the shield is pushed forward, to keep the face-rams stationary, still holding the poled face, by allowing them to come back relatively to the shield in a manner similar to that shown in *Figs. 13*, which represent the Greenwich shield doing such work. The cutting edge is provided with twenty-two teeth, and, in place of steel curtain-plates below the front diaphragms, 4-inch planks are used. The above method of working is not novel; it is similar to the plan adopted in the lower part of the Blackwall Tunnel shield, and described in the Paper[2] by Messrs. Hay and Fitzmaurice on that work. In that instance there were no face-rams in the shield, and a telescopic stretcher was employed. A special feature of the Lea shield is that the diaphragm and box are removable; and further, the front diaphragm is made in sections hinged together, so that in good material work can be carried on with an open face. This construction was adopted because it was known that, although most of the tunnel was in gravel, a considerable length was in water-tight clay, where special precautions would not be required.

The two shields of the trap kind with which the Author has

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[1] *Post*, p. 29.

[2] Minutes of Proceedings Inst. C.E., vol. cxxx. p. 71.

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had to work have given satisfactory results. No serious flooding of either tunnel under his charge has occurred; but on several occasions at Greenwich small inrushes of water, caused by a "blow" at the face, have happened; and the ease with which the water was held, immediately it rose high enough in the shield to seal the opening between the diaphragms, was noticeable.

The Greenwich Tunnel Shield.—The shield used in driving the Greenwich Tunnel is shown as originally built in Figs. 10, 11 and 12, Plate 1. Certain alterations, the nature of which will be indicated later, were made in it during the progress of the work.

The shield measures 14 feet 1 inch over all in length, and has an external diameter of 13 feet. The skin is formed of 1-inch steel plate, in seven segments, the longitudinal joints having 1-inch cover-strips. To prevent the cover-plates from stripping when the shield is in motion, the cast-steel cutting edge is thickened in front of them. The cutting edge is made in thirteen segments, each of which has two 6-inch teeth cast on it; and immediately behind the cutting edge is a circular built box-girder, 1 foot 8 inches by 1 foot 2 inches, to which it is bolted. The provision of this box-girder was specially insisted on by the Chief Engineer, and its insertion certainly ensures the shield keeping its shape. Further rigidity is given to the front of the shield by a vertical stiffener, 2 feet 8 inches in width and $\frac{3}{4}$ inch thick, bolted at top and bottom to both cutting edge and circular box-girder. Behind this is placed the front diaphragm, which closes the upper half of the shield, and extends downward (below the boxes containing the face-rams) to 1 foot 3 inches below the horizontal axis of the shield. Below this line are removable steel-plate curtains or shutters, which, however, were never used. The boxes containing the face-rams, 4 feet long, form part of the front diaphragm; for, though they are open towards the front of the shield to allow of the movement of the rams, they are closed at the back. The top and bottom plates of these boxes are bolted at each end to cast-iron segments of the kind usually employed in small shields for stiffening the skin; and the boxes are thus made to form a horizontal box-girder across the shield. In these boxes are placed the two face-rams, 5 inches in diameter, which were originally made to reach, when fully extended, only to the cutting edge of the shield. They were provided with sliding tables, the edges of which were supported on angle-bars fixed to the frame of the shield. The rams in this form were not accepted by the Chief Engineer without misgiving, and were consequently made so that they could

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be easily removed if found unsatisfactory. The idea in putting them in was that they would perform the same function which the loose needles did in the Mersey shield (*Figs. 9*, p. 12), in holding up the material in the upper part of the shield while the miners excavated at the bottom of the face. But in practice, when working in ballast, the ballast came in at the face below them as fast as the miners removed it, and the upper part of the shield in front of the diaphragm became blocked. Ultimately these tables were removed, and oak cross-heads were placed on the rams, which were lengthened; they were in fact made similar to those on the Lea tunnel shield (*Figs. 9* and Figs. 14, Plate 1).

Behind the rams is fixed the box which forms the back diaphragm of the trap. It is built in horizontal sections, which are removable, so that its height can be diminished if desired. The top of the box, which is fitted with lids having self-acting catches, is 8 inches above the bottom of the front diaphragm. This is sufficient overlap to form a water-seal, so long as the shield continues level; but as all circular shields rotate more or less in their advance, the effective overlap of the two diaphragms tends to become less as the shield progresses, and perhaps a greater overlap in the first instance is desirable. When the Greenwich shield had finished work it had a considerable tilt to the right, and the water-seal in the box was nearly non-existent. The thirteen rams for pushing the shield forward are of the usual kind. With a pressure of 1½ ton per square inch, they exert a total thrust of 750 tons.

Tunnelling.

The whole of the tunnelling was done under compressed air. The vertical air-locks in the Poplar shaft continued in use until 142 feet of the tunnel had been constructed, and then a bulkhead, with a horizontal lock and an emergency-lock above it, was built in the tunnel close to the shaft, and the upper air-tight floor and locks were removed and transferred to the Greenwich shaft.

When the plug in the tunnel-opening of the Poplar shaft had been removed, in the manner already described, the shield was pushed forward through the temporary clay face into the ballast. The handling of the shield when partly in the solid and partly under the opening in the shaft required great care; and at the outset considerable trouble was caused by carelessness on the part of a foreman, which, just as the shield was leaving the shaft, caused a fall of the face, and the formation of a large

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cavity above the front of the shield. The hole was filled with sawdust through the handholes in the front diaphragm; but in this operation another mishap occurred. By some means the sawdust became ignited, and for 48 hours a fire raged in front of the shield. It was soon found that the face-rams were too short, and further, that the sliding tables did not serve the purpose for which they were designed. For the time being their use was abandoned, and steel bars, about 6 feet in length, were used instead, passing through holes cut for them in the bottom of the front diaphragm. The method was exactly the same as that adopted with the Mersey shield, and some success attended it. At this time the face consisted almost entirely of ballast; and on the Author's recommendation, the contractors decided to abandon the use of sliding tables and needles for holding up the face, to lengthen the face-rams, and to utilize them for holding up the working-face by ordinary close poling. This answered well; and subsequently the method of working was further improved by excavating in front of the cutting edge, and filling the annular channel so made with clay—a method used by Brunel in the Thames Tunnel, and more recently by the engineers of the Waterloo and City, and Baker Street and Waterloo Railways.

Figs. 13 show the method of working, which is briefly as follows: the only difference from similar work previously done is in the use of the face-rams. Beginning at the top of the shield, the ballast was removed around the cutting edge down to the level of the top poling-board, which, when fixed, was in the first instance held in position by short timbers stretched from the frame of the shield; and similarly all the face of the ballast was poled, each poling being supported in the same way. The poling-boards did not extend the full width of the shield, but were in two lengths, thus allowing only half the face to be worked at a time, in places where the ballast was very open. Clay was put in front of the cutting edge, and doubtless it lessened considerably the work of the shield-rams; but the provision of teeth on the cutting edge has been found, as in the Mersey shield, also useful in this respect. When all the face was poled (*Figs. 13*, A), the face-rams of the shield were pushed forward, and, by means of soldiers, took the pressure of the face, the short timbers which had previously held the polings being knocked out. The shield was pushed forward, and as the cutting edge passed beyond the polings, the face-rams were allowed to draw back relatively to the shield, so that while the shield was advancing, the poled face remained unaltered. The position at the end of the operation is shown in

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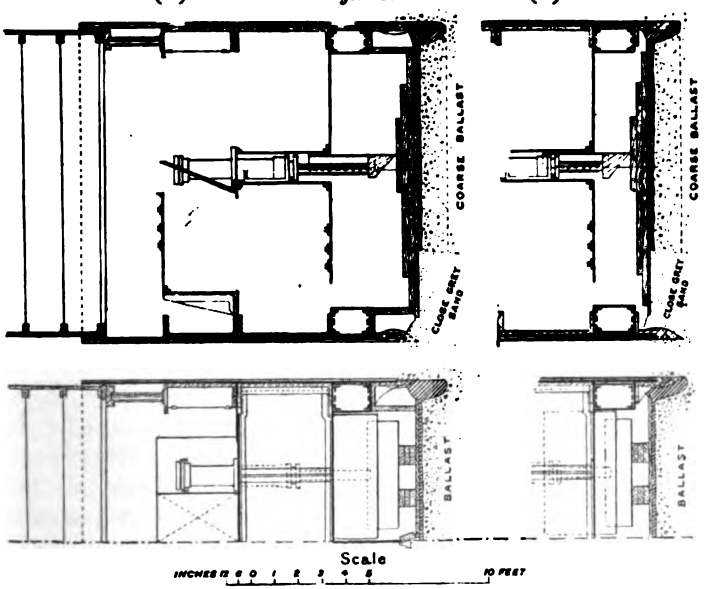
Figs. 13, B. The foregoing method of working was adopted in building the first 220 feet of the tunnel, which was mainly in open ballast with hardly any sand. This work occupied 3 months, namely, October, 1900, to January, 1901. On the 3rd January, the face being entirely composed of close grey sand, the use of clay at the face was discontinued; and when 430 feet of tunnel had been built, the face-rams were no longer used. A little farther on, several feet of close sand and clay were always found on probing above the shield, and the face itself consisted largely of shelly clay; consequently all timbering of the face was given up.

(A) *Figs. 13.* (B)



METHOD OF WORKING THE SHIELD.

From the character of the strata shown in Fig. 2, Plate 1, and from the rate of progress there indicated, it will be seen that during the months of January, February, March and April, 1901, the tunnel-work was of an ordinary character; in fact, the shield was worked as an open one until the gradient on the Greenwich side was reached. The front diaphragm had two doors cut in it, which were closed when necessary by short polings fitting into vertical guides at the sides of the doors.

When the shield reached the foot of the 1-in-15 gradient on the Greenwich side of the river, it was resolved, although the character

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of the ground continued favourable, to close the shield again; and the alterations indicated in *Figs. 9*, which had previously been fitted, came into use. The front diaphragm was not again closed, but the poling-boards already mentioned were kept in readiness on the shield; and a second diaphragm was placed 4 feet behind the original one, at the back end of the face-ram boxes, and in it was provided an opening with two double doors, the front pair opening towards the face and the other pair towards the tunnel. The inner pair were kept fastened by a short stretcher, which could be easily knocked away; and the door would then fly open with the rush of air through the shield (Figs. 14, Plate 1). The outer doors were ordinarily fixed open. In the event of any "blow" occurring, and a fall of the face blocking the ordinary egress through the trap to any men working in the top of the face, escape was rendered possible through these doors; and in practice it was found, when some small blows occurred, that the existence of this means of escape did embolden the men to endeavour to make things safe before leaving the face, instead of rushing out in a panic. The precaution was taken of placing two safety-diaphragms or curtains in the tunnel, at each end of the nearly level portion of the tunnel, that is, at the foot of the gradient ascending to each shaft. These diaphragms were of timber, and were about 3 feet deep from the soffit of the tunnel. If a serious blow had occurred while the shield was climbing the gradient towards the Greenwich shaft, the lower part of the tunnel might have been filled with water, and all escape for the men in the shield might have been cut off without this arrangement, by which a certain air-space was secured between the two diaphragms. A further precaution taken was to provide an extra blow-out pipe, controlled from outside the lock, which extended only to the bottom of the Poplar gradient, and thus afforded means of getting rid of any water which might come into the tunnel as the result of a "blow" when nearing the Greenwich shaft, and which would naturally collect in the lowest part of the tunnel, much below the level of the main blow-out pipe carried forward with the shield.

These precautions happily proved unnecessary, because the material met with for two-thirds of the whole distance proved to be highly favourable for tunnel-work; and when, on approaching the Greenwich shaft, a face almost entirely of open ballast was met with, the same procedure as had been adopted in the bed of ballast on the north side of the river again proved equally satisfactory. How favourable in general was the material met with

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may be judged from the fact that from the 22nd February to the 1st May, 1901, an advance of 10 feet was made every working-day without exception. In the open ballast on the Greenwich side of the river a uniform advance of 5 feet per working-day was made.

No difficulty was experienced in making the junction with the Greenwich shaft: the only precaution taken was to drive needles from inside the shaft, round the top of the steel plug, so as to form a hood over the shield when it reached the shaft, and thereby to prevent any fall of the ground above while the plug was being removed.

Conditions of Work under Compressed Air.

As at the Blackwall Tunnel, the London County Council made provision at Greenwich for the proper care and protection of the men working in compressed air; and the precautions taken during the progress of the work have been so far successful that the power taken by the Council, in the Act of Parliament authorizing the construction of the tunnel, to compensate men injured in health by working in compressed air, has been exercised in only three cases, and to a total amount of only £20. The County Council appointed Messrs. Leslie and Macmorran as medical officers at the tunnel, and the men working in compressed air were examined by them at least once a week: all men had at the outset to obtain a certificate of health from them before commencing work. It was found that, of the men presenting themselves for employment in the tunnel, 13·9 per cent. had to be summarily rejected; and of those who, having passed the first examination, worked for a longer or shorter time, 5·7 per cent. were subsequently found to be affected by the pressure, and were forbidden to continue working. Dr. Macmorran notes as a curious fact that some men who had previously worked in compressed air, and who, at their preliminary examination by him, were found to have deviations from the normal in their heart-action, but not sufficiently marked to justify their summary rejection, were found, after resuming work for some time, to have no trace of the irregularities at first observed.

The men worked in 8-hour shifts, with a rest of 45 minutes in the middle, during which interval they were not allowed to remain in the tunnel. Rooms with washing-requisites, etc., were provided for each gang, and hot coffee was served out to the men on leaving the tunnel. A medical lock was provided for treating cases of caisson-sickness but was used only twice. The

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amount of free air pumped into the tunnel averaged over 5,000 cubic feet, and never fell below 4,000 cubic feet, per man per hour. The air-inlet pipe delivered immediately inside the lock, and the blow-out pipe was carried forward with the shield. A simple arrangement introduced by the Author had a good effect in purifying the air in the shield. From the construction of the shield it will be seen that, particularly when the doors in the upper diaphragm were open, there would be little or no current of air at the bottom of the box of the shield, and consequently towards the end of a shift there was an accumulation there of carbonic acid. In fact there was frequently 0·2 per cent. by volume of CO_2 in the air within the shield, when there was less than 0·1 per cent. in the tunnel a few feet behind it. To remedy this, a pipe was passed through the back diaphragm or box of the shield near the top, and carried down inside nearly to the invert. Outside the box it projected a few inches, and on this projecting piece the nozzle of the blow-out pipe was placed whenever it was not in use for blowing water from the bottom of the tunnel. By this arrangement nearly all the air blown out through the pipe was taken from the place where most carbonic acid collected. Samples of air, taken on two occasions before and after using the blow-out pipe in the shield as described, showed a decrease in a few minutes in the amount of CO_2 present in the air; and had the pipe been fixed to the shield and controlled from outside the tunnel, the air in the shield could have been maintained of equal purity with the air in the tunnel. As the pipe was removable, its use depended on the miners themselves; and every one who has had to do with tunnelling knows that one of the main obstacles in the way of ameliorating the conditions of work in compressed air is the difficulty of making the miners carry out orders, the object of which they imperfectly understand. For this reason it is to be feared that the ventilation described above was not kept working as continuously as it should have been. The condition of the air in the tunnel was generally satisfactory, and only nine cases of caisson-sickness occurred in all, mostly trivial in character and caused by indiscretion on the part of the sufferers.

The Author was instructed by the Chief Engineer to inquire into the possibility of purifying the air in the tunnel by eliminating some of the carbonic acid (which in ordinary air amounts to about 0·05 per cent. by volume) from the air pumped into the tunnel; and the London County Council made a grant of money for carrying out experiments with that object. At the time the experiments were authorized, the tunnel was more than half

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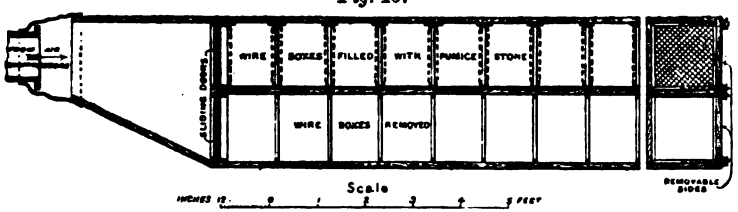
completed, and no serious alteration of the air-compressing plant was contemplated or possible. The engines were built by Messrs. Walker Brothers, and were entirely satisfactory in working; but from their construction and the arrangement of the engine-house, it was not possible in any way to box them in so as to arrange that all the air entering the compressing-cylinders should first pass through a purifying-chamber, or an installation similar to the purifiers or scrubbers used in gas-making. It was equally impossible to interpose a purifying-chamber between the engines and the tunnel, even if it had been permissible to incur the risk of a temporary break in the supply of air. Consequently the experiment was limited to trying what could be done in the tunnel itself under working-pressure. The simplest way of taking up the free carbonic acid in the air is by passing the air through or over a substance like lime or caustic soda, for which carbonic acid has a strong affinity. Probably at normal

Fig. 15.



PURIFIER FOR REMOVING CARBONIC ACID FROM AIR

pressure the former, used in solution in a scrubber, would be effectual; but a large quantity of lime-water is required even under favourable conditions, and to use such a quantity in the tunnel would have required more space than could be provided. A saturated solution of caustic soda is, bulk for bulk, more effective; and though the limited space available rendered it somewhat doubtful whether any marked results could be obtained by its use, a purifier of somewhat primitive design was constructed, and the results obtained with it were observed by officials of the Chemist's Department of the London County Council, who had also previously from time to time made analyses of the air in the tunnel.

The purifier is shown in *Fig. 15*, and consists of two rectangular trunks of wood, one above the other, open at one end, and having sliding doors at the other end. The ends fitted with doors are connected with the air-inlet of the tunnel by a conical box, the connection with the air-pipe being made air-tight by a

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flexible joint. By opening one or other of the sliding doors, the air is made to pass through either the upper or the lower trunk, as required. Each trunk has one side removable, and each contains eight removable wire boxes containing pumice-stone broken small, which, before being put into the trunks, are dipped in a saturated solution of caustic soda. When the upper trunk is filled with freshly dipped boxes, the door of the lower trunk is closed, and its boxes are taken out, dipped and replaced. The bottom door is then opened, and the top one closed, thus diverting the course of the air from the upper to the lower trunk; the boxes in the upper trunk can then be removed and dipped afresh in the caustic-soda solution. A constant relay of fresh boxes was kept up day and night; and the deposit of carbonate of soda on the pumice-stone soon showed that some effect was produced upon the air.

The purifier was in operation for a month, and analyses of the air in the shield were made on fourteen different dates. The results are given in the Table (p. 23), which shows, in addition to the amount of carbonic acid in the air, the air-pressure, the temperature of the tunnel as compared with that of the engine-room, and the amount of air supplied per man per hour, on the days when the tests were made. It will be seen that after the purifier had been taken into use, the average proportion of carbonic acid present in the tunnel showed a decrease on that observed before. If there were no other factors to be considered, such a result would be conclusive, but there are so many circumstances which modify the result that the Author would confine himself to saying that the apparatus employed was responsible for some of the improvement; and that, as some effect was produced by its use, a similar purifying-apparatus properly elaborated may reasonably be expected to eliminate the larger portion of the carbonic acid in the air.

The last two lines of the Table give the averages for all the observations before and after fitting up the purifier. The average diminution of CO_2 by volume, apparently consequent upon the use of caustic soda, is 0·01 per cent. The average amount of free air supplied per man per hour was a little less, and the pressure per square inch 3½ lbs. less, after the purifier was put in, than previously: so that these two important factors in determining the amount of CO_2 in the air do not vary much. The variations in the quantity of CO_2 in the free air of the engine-room are probably caused by momentary contamination of the air, due to the proximity of the boiler-furnaces. The samples

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of air in the tunnel were taken at floor-level; and the percentages

Date.	Air-Pressure per Square Inch.	Temperature in Shield above or below that of Engine-room. Fahr.	Free Air Supplied per Man per Hour.	Percentage of CO_2 by Volume.			Remarks.
				In Engine-room.	In Tunnel.	In Shield.	
1901.	Lbs.	Degrees.	Cub. Ft.				
March 5	24	+10	6,000	0·047	0·073	0·196	Men working.
„ 11	21	+19	5,280	0·055	0·097	0·218	End of shift.
„ 18	24	+15	5,600	0·045	0·064	0·189	„ „
„ „	..	..	..	..	..	0·124	After blow-out pipe had been used.
„ 25	23	+15	5,280	0·047	0·058	0·125	End of shift; blow-out pipe used four times.
„ „	..	..	..	..	..	0·098	After blow-out pipe had been used.
April 1	25	+13	5,280	0·051	0·087	0·186	Men working; blow-out pipe used at intervals.
„ 15	26	+ 6	5,280	0·049	0·084	0·173	„ „
„ 22	24	− 7	5,280	..[1]	0·098	0·223	..
„ 29	22½	−10	5,280	0·043	0·080	0·170	Blow-out pipe in use.
May 6	17	+ 5	7,000	0·049	0·076	..	Shield closed.
„ 13	18	− 2	7,460	0·042	0·069	0·100	..
„ 15	..	..	..	..	..	..	Purifier in working order.
„ 20	19	− 2	5,900	..[1]	0·056	0·097	..
„ 22	17	− 3	6,000	0·067	0·074	0·111	..
„ 24	16	− 3	6,870	..[1]	0·072	0·126	..
„ 27	18½	− 7	7,195	..[2]	0·066	..	..
„ 29	17	− 9	6,580	0·047	0·077	..	..
„ 31	23	+ 1	5,280	0·052	0·073	..	..
June 3	21	+ 5	5,280	0·049	0·075	..	..
„ 6	20	+ 1	5,430	0·068	0·077	..	..
„ 7	18	+ 1	5,430	0·059	0·057	..	..
„ 10	20	− 5	4,260	0·042	0·066	..	..
„ 11	21	..	4,240	0·039	0·072	..	Doubtful.
„ 12	20	+ 5	4,100	0·045	0·068	..	..
„ 13	19½	+ 6	4,500	0·039	0·062	..	..
„ 14	18½	+ 2	4,260	0·049	0·068	..	..
..	22½	+ 6½	5,774	0·0475	0·0786	..	Average before using purifier.
..	19	..	5,330	0·0505	0·0688	..	Average when using purifier.

given in the Table are the averages of two and sometimes of three

[1] Sample spoilt. [2] Sample spoilt. Shield in south shaft.

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separate samples, one of which was always taken a few yards behind the shield. On the whole, the results of the analyses are encouraging; they appear to show that the purifier produced some beneficial effect.

It is generally agreed that the disease known as caisson-sickness is due to four causes, which react on one another; namely, excess of carbonic acid in the air, excessive air-pressure and limited supply of air, and prolonged continuous exposure of the miners to these conditions. Of these causes of illness, two—namely, the amount of air supplied per man per hour, and the duration of the working-shifts—are strictly regulated by clauses in the contracts, in all works carried out for the London County Council. It would be no small advantage if a third cause of ill-health, and that the most dangerous of all, could be, if not eliminated, at least lessened in effect, by the use of mechanical scrubbers containing some absorbent of carbonic acid. At small extra cost in the first installation of an air-compressing plant, arrangements could be made for passing all the air to the compressors through a purifier; or perhaps a combination might be made of a spray purifier, which at the same time should cool the air on its way to the tunnel. Such a combined cooler and purifier would of course be placed on the pressure side of the engines.

The work was carried out under the supervision of Sir Alexander R. Binnie, M. Inst. C.E., Chief Engineer to the London County Council, for whom the Author acted as Resident Engineer. Mr. James Brown, Assoc. M. Inst. C.E., was Agent and Engineer for the contractors, Messrs. J. Cochrane and Sons.

Mr. C. E. Gaunt and Mr. E. G. Carey acted as Inspectors of steel and cast-iron work for the London County Council; and, as already mentioned, Messrs. Leslie and Macmorran were the Medical Officers in charge of the compressed-air gangs.

The Paper is accompanied by eleven drawings, from which Plate 1 and the Figures in the text have been prepared.

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(*Paper No. 3317.*)

"Subaqueous Tunnelling through the Thames Gravel: Baker Street and Waterloo Railway."

By ARTHUR HARRY HAIGH, B.Sc., M. Inst. C.E.

By the original Parliamentary Acts of 1893 and 1896 the Baker Street and Waterloo Electric Railway was authorized to be constructed from Dorset Square to Waterloo, in two cast-iron tunnels, forming a double line with a length of 3 miles 1 furlong 1·3 chain. The route is beneath the Baker Street Station of the Metropolitan District Railway, by Regent's Park and Crescent Gardens into Portland Place, through Langham Place and Regent Street to Oxford Circus, where the tubes pass over those of the Central London Railway (the clearance over one of them being only 6 inches), down Regent Street to Piccadilly Circus, along Haymarket and Cockspur Street to Charing Cross, thence down Northumberland Avenue, and under the Thames to College Street, Vine Street, and Waterloo. Foot-passage connections will be provided with the Great Central Railway station at Marylebone Road, with the Metropolitan lines at Baker Street, with the Central London Railway at Oxford Circus, with the District Railway at the Embankment, and with the London and South Western main line and the Waterloo and City line at Waterloo. Access to the line will be afforded by lifts at the stations in the modern way. In addition to the stations at the connections referred to, there will be others at Piccadilly Circus and at the Nelson column at Charing Cross. Most of the permanent shafts for lifts and stairs, and the greater portion of the 6 miles of tunnel, have been constructed. Excepting the river portion, the whole length of the tunnels is through London clay; and what is generally known as the Greathead shield is employed for construction. This Paper, however, is limited to a consideration of the special river portion.

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Subsequent Parliamentary Acts authorize the extension of the railway at the south end from Waterloo to the Elephant and Castle, with sidings and an electric generating-station on the present site of the School for Indigent Blind near St. George's Circus; and at the north end from Dorset Square to Bishop's Road, Paddington.

The Gravel.

Between the bottom of Northumberland Avenue on the left bank of the river and the west end of College Street on the right bank, the tunnels pass through a bed of clean gravel and sand, lying in an abrupt depression of the surface of the London clay to at least 45 feet below its general level. This feature necessitated construction under compressed air. The foundations of the Charing Cross Railway Bridge, 250 feet away, gave no indication of this depression, which was found during the boring-operations that were conducted as necessary preliminaries to the final location of the centre-lines of the tunnels, and to the commencement of the temporary works for construction. The profile of the clay surface through this depression, and along the centre line of the tunnel lately constructed, which had been determined from borings not exactly on the adopted centre-line, corresponded closely with the surface actually encountered during construction, where it was capable of being so tested; and the guidance it afforded was sufficiently exact for all practical purposes.

Location of the Tunnels.

The two tunnels, 12 feet in internal diameter, for traffic in the two directions, were located through the gravel bed 23 feet apart from centre to centre in plan, giving a clear space of over 10 feet between their horizontal diameters (Fig. 1, Plate 2). Northward this distance between centres diminishes from 23 feet at the left bank of the river to the normal distance of 17 feet 6 inches in Northumberland Avenue; and southward, from 23 feet, near low-water mark on the right bank, to zero in College Street, where the east tunnel will be vertically over the west tunnel, in order that both may pass within the confines of the narrow street. The gradients of the tunnels over this portion were arranged so that, with a gentle downward slope of the one and a similar upward slope of the other, the relative positions in College Street could be attained without reducing the minimum thickness of clay between them to less than 3 feet 6 inches. These gradients, as will be seen from

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the section (Fig. 2, Plate 2), are 1 in 107 down, southward in the west or down tunnel, and 1 in 111 up, southward in the up or east tunnel. In plan (Figs. 1) the centre-lines curve from the river into Northumberland Avenue by 12-chain curves, and into College Street by 15-chain curves.

Shafts.

In the preliminary arrangements for construction it had been intended to make a timber stage on piles driven into the river-bed near the right bank, from which temporary shafts might be sunk to the tunnel-levels, and from which a bridge might lead to the shore at the end of College Street—similarly to the method used for the Waterloo and City Railway. The depression in the surface of the clay necessitated a re-consideration of the method of opening out. The Thames Conservancy courteously agreed, without any difficulty, to permit the erection of a stage 150 feet from the left bank of the river, near the wall of the Victoria Embankment; and the South Eastern Railway Company permitted a temporary footbridge from the stage to the shore to be carried on cantilevers attached to the Charing Cross Railway Bridge.

In this position a timber stage 50 feet wide was constructed on piles, extending 370 feet up-stream from the first cylinder-pier of the bridge in the river on the Embankment side. From this stage, shafts of cast iron, 16 feet in internal diameter and 50 feet in depth, were sunk, and brick chambers were constructed below. The stage holds all the necessary shops, stores, buildings and machinery. Along each side crane-roads, of 6-foot and 4-foot 8½-inch gauges, were laid on longitudinals. From these roads travelling steam-cranes, having a horizontal radius of 20 feet, are able to command barges lying alongside, and the middle of the shafts. The boilers, air-compressors, and dynamos are described in the Appendix. Below stage-level are two boiler-shaped air-receivers and a condenser, in a caulked water-tight wooden chamber below high-tide level. Near the shafts are the engine and mixing-pan for the pugged clay so extensively and effectually used at the face. The portion of the stage occupied by the engine-houses, boilers, and offices, is decked with Portland-cement concrete, with lengths of wrought-iron joist and girders built into it. Against short cross joists in the concrete, long raking struts of whole timber are butted, footing against the piles. Eight pairs of these struts form a rigid support, and the simultaneous use

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of all the air-compressors does not cause perceptible vibration. The remainder of the stage is decked with two thicknesses of planking.

After boring-operations through the river-bed, occupying more than 3 months, the first pile of this stage was driven on the 20th June, 1898, and the structure was practically completed early in the following November. The stage stands 6 feet above Trinity high-water level, and on the average has 27 feet of water around it at high tide. The two temporary cast-iron cylinders, 16 feet in internal diameter, consist of six rings, each 8 feet in depth, having six segments to a ring. The joints were machined, and the pieces were put together with red lead and hemp-yarn. A 2-foot cutting edge, with bevelled vertical flanges and sharpened edge, was used to sink the cylinder. Six rings and the cutting edge make up the 50-foot length of iron cylinder, reaching about 10 feet into the London clay. Below this the brick chamber extended downwards a further distance of 22 feet. To prepare for sinking the cylinder, a timber platform was erected, somewhat above the level of low water, and on it the cutting edge was put and bolted together. The two succeeding rings were then built above, and the length was slung by chains, and held by union screws from timber balks across the opening in the stage-decking. The platform below was next removed, and the 18 feet of cylinder was lowered through the mud, the grab being used within, until, on its taking a bearing, the screws could be detached, when another two rings were built. Including the weight of the cylinder, a load of 106 tons, equivalent to about 2½ cwt. per square foot of maximum surface exposed to friction, sufficed to sink the remaining 6 feet to the required level for underpinning the cylinder with the brick walls, 23 inches thick, for the enlarged chamber below. In carrying down the brickwork, spaces were left for eyes, in which five-ringed brindled brickwork in 2 to 1 Portland-cement mortar was afterwards built, forming complete circles through which the tunnelling-shields were to be driven, the work above being propped in the meantime. Each leg of succeeding rings of brickwork was built under the junction of two legs of its predecessor. Inverts were made of 15-inch Portland-cement concrete, dished about 6 inches.

From No. 1 shaft, in the "down" or west tunnel, tunnelling northward was begun in February, 1899. The south faces stood until the 22nd March, 1900, when the shield was driven through the eye of the west tunnel.

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The Shield.

In bad ground the ordinary shield affords no protection in front of the cutting edge to the men working in the "length." Consequently, its use then involves the driving of a top heading, from which the length is opened by timbering downwards. The shield is then driven through the length and the timber is built in, as was done on parts of the City and South London and Waterloo and City Railways, in passing through gravel south of the river. Not only is much timber thus built in, involving expense and also liability to future settlement of superincumbent soil owing to its decay, but also, while the shield is being driven, considerable disturbance of the material is caused by movement of the timbers, with consequent risk to the stability of the face. The strata to be dealt with in the Baker Street and Waterloo Railway tunnels—very open ballast charged with water directly beneath the river under a head of 70 feet at high tide—did not permit of such a risk being incurred. Apart from the absolute danger of collapse of the face, it would have been extremely difficult to render moderately air-tight such a timbered space, with so large a proportion of top or roof where the escape was most ready; and the large and sudden losses of air which would have resulted would have necessitated extensive plant and involved heavy pumping-expenses, even if the requisite pressure could have been maintained at all. In the actual construction a small area of exposed face involved such a rapid loss of air that every portion had to be thickly plastered with pugged clay as quickly as possible. The adoption of a hood in front of the shield, as used on a portion of the Waterloo and City Railway, obviated the difficulties referred to: the hood is simply a prolongation forward of the cylindrical skin of the shield at the cutting edge, except only at the invert, where the edge is cut away, for affording access to the uncovered ground for working.

It was important to provide for the safety of the men in the event of a "blow," which would be of likely occurrence with such open ballast, and also to prevent flooding of the tunnel. This was effected by attaching, within the circle of the ram-casting, a fountain trap, as applied to the shield used in the construction of the Mersey aqueduct tunnel.[1] In advance of the upper screen of the trap there was just sufficient working-space for the miners; and the screen was so close to the men that they had no difficulty

[1] *Ante*, p. 11.

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in escaping under it when a "blow" occurred. But in a shield of this size space was insufficient for the use of shutters at the narrowing vault above the miners' heads; and a pair which were tried at the top were forthwith abandoned. Both were badly bent at their narrowing ends, evidently from the attempt to screw them forward without having effectually cleared away the ballast in front of these ends. In this respect the circumstances were essentially different from those of the Blackwall Tunnel, where the size of the shield for a 27-foot tunnel permitted access to the shutters for removing the material with facility. It was originally intended to use shutters down the whole face; but the top pair having been abandoned, it was found more convenient to continue the timbering downwards as a homogeneous system than to apply shutters below with timber above.

Figs. 3, Plate 2, show the shield, weighing 29½ tons, made by the Widnes Foundry Company from drawings sent out by the contractors, Messrs. Perry & Co., after consultation with the engineers. Its outer casing consists of a steel cylinder 13 feet in external diameter, having the lower part in front cut away, in a curved form, from a maximum height of 3 feet at the cutting edge, thus leaving a hood or cover above an open invert. The middle portion of the shield's length covers the rams, and the back part forms the tail space for erecting the iron tunnel-rings. The edges of the plates at the front of the hood are bevelled at an angle of 45° to form a cutting edge. The circular box-girder, 10 feet 1 inch in internal diameter, and the middle vertical girder within it, form the main frame or rib of the shield. The several thicknesses of steel skin at the hood are connected by nine circular rows of 1-inch rivets with 6-inch pitch, and one row of 3-inch pitch close to the bevel of the cutting edge; all have their outside heads countersunk. The segments of the several layers of the skin break joint; and cover-strips run the whole length of the shield over the outermost six longitudinal joints. Nine gussets connect the side plate of the box with the skin of the shield. The whole length of the shield is 9 feet 8½ inches; which may be divided into, main body 5 feet, tail 2 feet 6 inches, hood 2 feet 2½ inches. Within the main body, behind the circular girder, is the cast-steel ring bearing the fourteen hydraulic rams, each 6 inches in diameter, eight clustered at the lower parts and six set in pairs laterally (Figs. 4 and 5, Plate 2). Ordinarily the lowest four were not brought into use; and six or more of the remaining ten were suitable and sufficient for driving the shield. Each ram is capable of being actuated independently. The rams, of cast steel, are 1½ inch thick, and have a stroke of

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20 inches. All the cylinders, pipes, valves and connections are adapted to stand a hydraulic pressure of 2,400 lbs. and were tested to 3,500 lbs. per square inch. Working-pressure is supplied to the rams by an intensifier, having a cylinder 7 inches in diameter, fed by the London Hydraulic Power Company's water from their mains in the Embankment, at about 800 lbs. per square inch; and the pressure on the piston of the intensifier is transmitted by two plungers 3 inches in diameter to the water in communication with the rams. The calculated multiplication is 4⅓, and an effective result of 3 is allowed. The usual average pressure on the rams when in action is about 1,300 lbs. per square inch.

The safety-appliance, which may be described as a fountain trap, was formed by closing in the lower half of the shield, 3 feet behind the box-girder, by a vertical steel plate reaching upward above the centre of the shield; and similarly closing in the upper half by a plate against the box-girder, and therefore 3 feet ahead of the back plate, and reaching downward 6½ inches below the lip of the back plate. A bird's drinking-fountain illustrates the principle of action of the shield trap: the domed reservoir holds a supply of water, which would flow away through the supply opening at the bottom, were it not that, the air-pressure being superior to the hydraulic head, flow from the reservoir ceases as soon as the supply opening is immersed. The apparatus effected automatically, in case of emergency, the change of a face ordinarily vertical to one horizontal, forming, in case of a blow, a seal by the action on the horizontal surface of water in the trap of an air-pressure superior to the hydraulic head beyond the diaphragm. This arrangement acted quite satisfactorily, the occurrence of a few blows from time to time showing that the four men at work between the diaphragm and the face had time to escape through the trap, and that, on filling, the trap sealed automatically, maintaining an unstable equilibrium, until the sand, which followed from the face, filled the trap, and extended with a sloping surface from the lip of the diaphragm to the face at the cutting-edge soffit. It was possible to remove this sand subsequently, by opening carefully under the edge of the diaphragm, until a miner could gain access to the face, and set protecting timber. The top of the trap was provided with a plate with a manhole through it, and a covering lid which could be screwed down in case of need. Round iron foot- and hand-bars were fixed up the curved sides of the trap and inside the circular girder. The semicircular diaphragm-plate and the back vertical plate of the trap were pierced, each with two holes, for the four hollow round steel struts, for holding the face timbers independently

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of the shield. When in position, these struts passed through leather sleeves, 18 inches long, attached to the steel plates on the pressure side by angle-bar rings and bolts (Figs. 11, Plate 3).

Iron Lining (Figs. 6–9, Plate 2).

The special tunnel-rings of cast iron for the length in river-gravel consist of seven segments, four of one pattern having longitudinal radial joint-flanges, and two having a radial flange at one end, and at the other a flange set at an angle to meet the tapered flanges of the short key-segment, which is 10 inches wide outside and $10\frac{1}{4}$ inches inside. These seven segments form a ring 18 inches long, 12 feet in internal and 12 feet $9\frac{3}{4}$ inches in external diameter, and weighing 1 ton 15 cwt. 1 qr. 16 lbs. The metal skin is 1 inch thick, and there are 53 bolts at each circumferential joint. The joint between two segments bisects the pitch-distance between two bolt-holes. The rings are placed joint opposite joint, forming a tunnel with continuous longitudinal joints. Circumferential joints were caulked with iron-rust cement. When the use of the special rings was begun, both circumferential and longitudinal joints were machined; but for the bulk of the work the circumferential joints were left rough, and put together with creosoted pine-wood packing. Machined joints were painted with a mixture of red lead and Stockholm tar, before being put into the tunnel. Numerous grommets were put around bolts to ensure water-tightness. The grout-holes provided in the key-segment and the two segments next to it were tapped, and were stopped with steel screw-plugs after grouting. The grouting-mixture used throughout was 3 of blue lias lime with 1 of clean sharp sand. The grouting-machine is shown in Fig. 10, Plate 2. The ordinary cast-iron ring used in London clay is 20 inches long.

Tunnelling.

The shield for the west or down tunnel was built in the chamber at the bottom of the shaft during January, February, and March, 1900, and tunnelling was begun on the 19th March. For guiding the shield the usual method of plumb-bob lines and boning-rods was used. Side rods, graduated in feet and inches and passing over fixed index-marks set square to the centre-line, were drawn along by the shield to gauge the equality of its lateral advance; and a suspended bob-line on the shield itself indicated its position for maintaining the advance on the requisite gradient,

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or for correcting any want of exactness in position as regards level. When travelling on the curve, one of the side rods bore a shrunk scale to correspond. The centre-line below was taken from a 15-foot 6-inch base, transferred down the shaft by wires set in position from the embankment-wall 180 feet away.

On leaving the shaft the shield had a cover of clay 17 feet thick, and was 24 feet below the river-bed. Driving under ordinary atmospheric conditions was continued until the 2nd April, when the advance was suspended in order to build the bulkhead wall with air-locks behind the shield. At that time there was still 15 feet of clay above the crown of the tunnel. A wall, 8 feet thick, of wire-cut gault bricks and Portland-cement mortar, grouted with neat cement by air-pressure through iron pipes built in for the purpose, formed the air-tight diaphragm. Besides the working-lock 5 feet 9 inches in diameter and 13 feet 6 inches long, and an emergency-lock above it 3 feet 9 inches in diameter, all the necessary pipes and electric wires were built in as the brickwork rose.

The shield was re-started on the 2nd May after one month's interval. On the 21st, when the clay showed a change in quality, the shield was stopped, and the fountain trap at the back was attached. The cover of clay at the cutting edge was then 5 feet, and the depth below the river-bed 18 feet. Hitherto a box heading, with 6-foot timbers for head and side trees resting on sills, had been worked in advance of the shield to a distance of about 7 feet. This was now stopped. Auger-borings were being made in the length each time the shield was driven forward, extending to 5 feet above and in advance of the cutting edge; they were also made in advance of the box heading. On the 23rd May the lock-doors were closed, and an air-pressure of 10 lbs. per square inch was maintained. After building-in the locks and re-starting the shield, one engine had been running and blowing air into the tunnel in readiness for closing the doors at any time.

On beginning compressed-air work the labour-shifts were altered from two 12-hour to three 8-hour gangs. On the 6th June the cutting edge entered the gravel at the soffit. For about 3 days previously there had been practically no thickness of clay cover; and the vertical face at its upper part was poled up and down, middled by a waling, and the top of the length was guarded by a few boards. When ready for driving, the short stretchers against the shield were struck, after substituting a waling low enough to be held by the hollow steel struts which passed through the diaphragm-plate, and were blocked against a transom 9 inches by 8½ inches, secured in the flanges of the last-built ring of tunnel

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(Figs. 12, Plate 3). Two pairs of these hollow struts were provided. Each was 5½ inches in diameter, closed at the forward end by a screw plug, which was shouldered flush with the outer cylindrical surface of the strut, so as to form a solid butt against the face timbers; while at the back or tunnel end was a similar plug, but tapped with internal screw-thread, through which worked the screw bearing the round ram-head and perforated with holes for lever-bars, for tightening against the transom. Each pair of struts passed through the holes in the diaphragm-plates of the fountain trap. As soon as the thickness of the clay cover above the cutting edge had diminished to only 2 or 3 inches, hand holes or pockets were opened, in advance of the face and in front of the cutting edge, reaching a few inches above it, and rather more than one length in advance, into which well-tempered clay was put, precisely in the manner described by Mr. H. H. Dalrymple-Hay in his Paper[1] on the "Waterloo and City Railway," as used there with the hooded shield; a series of such pockets formed finally a continuous portion of an annular bed of soft clay, into which the cutting edge could easily enter. The circumferential length of this annular bed grew as the amount of ballast face increased, until it extended round the whole hood; thus forming, as the shield advanced, an air-seal at its tail where the last tunnel-ring had been built, and affording a clear space for the grout to enter around the tunnel. As the ballast face grew downward a second row of poling-boards was introduced below, with a middle waling 9 inches by 4 inches; the two walings were held by soldiers 11 inches by 6 inches, and by the upper pair of steel struts, when the shield was being driven (Figs. 13, Plate 3).

On the 16th June the special 18-inch lining-rings were first employed. There was then 15 inches of ballast at the face, and a cover of 22 feet to the bed of the river. When the ballast extended down 3 feet 6 inches, which was the length of the upper polings, it was found desirable to substitute horizontal planks for the vertical upper polings, which exposed too high a portion of the face on removal; two sets of vertical polings continued to be used against the clay below. Each of the three uppermost widths under the hood consisted of two pieces, while a few below them were long planks across the whole face (Figs. 14, Plate 3).

From the 21st to the 27th June the top pair of iron shutters was used. In addition to the difficulty of limited space for

[1] Minutes of Proceedings Inst. C.E., vol. cxxxix. p. 25.

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using them, the range of movement was so small that setting forward the face for one tunnel-ring required double labour, that is, setting forward twice. Suitable progress under such circumstances was not possible; and the crippling of the top pair of shutters soon proved that the miners' patience was unequal to the task. Horizontal timber members, in two parts across the face, were therefore substituted. When the face-planking came into use as far down as the lower pair of steel struts, the planks were held by soldiers and walings against the steel struts. Figs. 12–19, Plate 3, show the face-timbering used at various stages, at the dates noted thereon. The face was set forward to a position varying between 2 feet 2 inches and 2 feet 6 inches beyond the front edge of the vertical girder. The whole of the gravel portion of the face was thickly plastered with pugged clay, against which the planks were set.

On the 15th July there was a full face of ballast. On the 21st a run of water filled the fountain trap. On the 20th and 21st August blows occurred, filling the trap with water, followed by ballast which choked itself in the shield. The four men at the face escaped safely under the diaphragm-plate, and were able subsequently to attack the face again by getting into one half-section of it at a time, the vertical girder forming a divisional guard exactly adapted to the circumstances. On both the latter occasions it was the uppermost planks which were blown in. It is probable that on the 20th August more timber than a single width of board was removed simultaneously for setting forward; the rule was one width only. After the second of these two blows the space of the five uppermost planks was found exposed, the blow occurring when the lower portion of the face, at about floor-level, was being set forward. Possibly, therefore, there was lack of vertical support, through insufficient inclination of the temporary props to the face-planks; thereby allowing a slight downward movement of the boards, and a consequent loosening which permitted the uppermost planks to blow in. Or else the pugged-clay stopping at the cutting edge was insecurely held at some place, allowing an escape of air and a loosening of a mass of pugged clay, by the oscillation of hissing air and the opposing water pressure outside; and such a mass, dropping out of its place, involved a sudden loss of air-pressure, and a rush of water, scouring the face and freeing the planks.

On the 14th September the last blow occurred, which filled the fountain trap with ballast. This also was successfully dealt with, but involved delay.

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On the 21st September a good deal of water was let into the tunnel from deficiency of air-pressure; but only near the face was the rail-road awash. From this time until getting completely into the clay the ballast was coarse and open; and the air escaped so readily through it that difficulty was experienced in keeping up the requisite pressure. The blow-off valve of the air-receiver was regulated automatically by a float on the river, which carried a vertical board having an inclined channel-bar groove attached to it. The groove constrained a roller, which moved horizontally as the board rose and fell with the tide, and varied by its movement the position of the fulcrum of the loaded valve-lever, thus varying the pressure according to the hydraulic head.

The specific gravity of the ballast was found to vary between 1·42 and 1·60; the average weight was 96 lbs. per cubic foot, or 1·55 specific gravity. A mass of the ballast became fully charged with water by the addition of between one-fourth and one-third of its volume; the specific gravity of the mixture varied between 1·75 and 1·85, and the average weight was 112 lbs. per cubic foot, or a specific gravity of 1·80. The specific gravity of the solid flinty constituents was 2·13, or 133 lbs. per cubic foot. As the iron tunnel weighs about 2,620 lbs. per lineal foot, the buoyancy of the tunnel, 12 feet 9¾ inches diameter, in water, is 8,114 lbs. − 2,620 lbs. = 5,494 lbs. per lineal foot. The counterbalancing downward pressure of the weight of 1 foot thickness of ballast above the tunnel is $62{\cdot}42 \times (1{\cdot}8 - 1)$ lbs. per foot of diameter, equal to 640 lbs. over the tunnel diameter. The cover of ballast therefore necessary for a balance of buoyancy and superincumbent weight is $5{,}494 \div 640 = 8\frac{1}{2}$ feet about; say, allowing for the slope of the haunches, 8 feet. Under that depth of ballast in the water the weight of the tunnel and the load above would be just supported by the fluid pressure.

On the 27th September the tunnel re-entered the London clay at the invert, and on the 6th October a full face of clay was again obtained. During straightforward work, normal progress with a ballast face was three 18-inch rings per day of 24 hours.

On the 8th October the use of ordinary 20-inch rings was resumed; and a box heading was again begun, driven as low as possible. On the 24th, at low tide, all the compressed air was let out to test watertightness. There were droppers through bolt-holes and some joints as the tide rose. Air-pressure was then restored, in order to fix grommets on bolts and to recaulk some joints. On the 27th the compressed air was finally dispensed with; and on the 8th November the removal

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of the lock-wall was begun by attacking it with drills. The water-spout at the river-surface over the tunnel-face, which for some months had been a feature visible from either bank, had now ceased to rise. It had sometimes risen to about 2 feet 6 inches above the surface, forming a picturesque cap to the invisible column of air ascending through the ballast and water from the working-face. The column was usually deflected from the vertical by the tide. At some positions a deviation occurred due to other causes—probably to the different degrees of openness of the material through which the air ascended. It was found during tunnelling that at some places the beds of different materials alternated rapidly. Sometimes two air-spouts were delivered, a considerable distance apart. In addition to forming these spouts, the air escaped in innumerable frothy bubbles over a large area above the tunnel-face.

Work under Compressed Air.

During the whole period whilst the face or any portion of it was ballast, the air-pressure maintained in the tunnel was equal to the hydraulic head of the tidal water. The daily range of air-pressure was therefore ordinarily between 24 lbs. and 32 lbs. per square inch above atmospheric pressure. Whenever, by reason of the rapid escape of air, the engines were unable for a time to maintain an air-pressure equal to the hydraulic head at the invert, the depth of water standing in the length at the front of the shield corresponded exactly with the difference of pressure. Often, with a boxed face well pugged, the engines delivered more air than escaped, and at high-water the air-pressure rose to 35 lbs. per square inch. With such deficiency and excess of pressure the range was between 21 lbs. and 35 lbs. per square inch. While the three engines were running at full speed, atmospheric air was being pumped through the tunnel at the rate of 200,000 cubic feet per hour; but with a clay face sometimes only 30,000 cubic feet of air per hour was blown through, with one engine only at work.

From the 23rd May to the 27th October, a period of 157 days, during which compressed air was employed, one hundred and twenty miners and labourers were at work during some portion of the time. As three gangs worked daily, ordinarily in 8-hour shifts of thirteen men each, there were, on the average, three complete sets of the full complement of thirty-nine men. Twenty-eight men worked practically throughout the compressed-air work. Eight—who began somewhat later—had a total record on the time-sheet as

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high as several of the former, making with them thirty-six men who worked regularly through the bulk of the compressed-air construction. Thirteen others worked altogether half time of the whole period. One man worked 41 consecutive days, one 40 days, and another 35 days. The last continued at work to the end of the special construction, totalling the highest number of days worked, viz., 129; in addition to which on eight occasions he worked two shifts in one day. Another, almost as pertinacious, totalled 125 days, with 31 days of consecutive labour. Among the whole number thirty-two men worked less than 10 days each. Out of one hundred and seventeen men twenty-eight worked all through, six a large portion of the whole time, thirteen about half time, thirty-six casually, and thirty-two for short periods.

Dr. Frederick Wainwright, the medical officer appointed by the contractors to examine the labourers in the compressed-air work, and to attend to cases of sickness affecting them, reported that, out of the one hundred and twenty men he passed, eighty-eight had previously worked in compressed-air, thirty-two having had no previous experience of it. Forty-seven cases of illness came under his treatment, which occurred among forty different men, two of whom had three attacks, and three of them two. He was of opinion that none escaped a slight twinge of pain at some time or other. Details of his observations and cases are published in the *Lancet*.[1] The pathological effects of compressed air, as manifested during this work, were of two kinds. The minor effects were the direct result of the actual mechanical pressure during the change in the lock; the more serious effects, the real "bends," as they are called, were due to other causes, and appeared some time after egress, and only after a lengthy stay in the compressed atmosphere. The symptoms of the former are chiefly pains in the ears, and slight bleeding from the nose; of the latter, pain, usually in the joints, and often very severe.

Apart from undergoing the condition of changing the pressure in the air-lock, the effect of an atmospheric medium under higher pressure, for living and working in, does not seem as a rule to be deleterious, at any rate up to a pressure of about three atmospheres. It is true there are many individuals for whom it is unsafe to go into compressed air; for, under working-conditions, they must frequently be subjected to variations of air-pressure, and occasionally to more highly dangerous incidental circumstances. There are three factors which appear to govern the occurrence of compressed-air sickness:

[1] 22 December, 1900.

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namely, the amount of the pressure, the proportion of carbonic acid present in the atmosphere, and the length of stay in the compressed air. These might be shortly designated as pressure, purity of air, and time. Cases of "bends" appear to occur only after 3 or more hours' stay in the compressed air, and mostly when the purity of the atmosphere is below a certain standard. As a rule in this tunnelling, in view of the difficulty of preventing a large escape of air at the face, the compressed air was delivered immediately at the lock end, and traversed the whole length of tunnel before egress at the face, thus effectually displacing the older and more contaminated atmosphere. As the tunnel and the work at the face were well lighted electrically, the vitiation of air was reduced to a minimum. With a gravel face the carbonic acid was 0·06 to 0·07 per cent. by volume of the compressed atmosphere; while with a clay face 0·08 to 0·10 per cent. was registered. The largest quantity delivered per man per hour, in the purest condition, was equivalent to about 13,000 cubic feet of air, measured at ordinary atmospheric pressure. Under the worst conditions, only between 1,300 cubic feet and 2,000 cubic feet per man per hour was delivered. Between the 23rd May and the 4th October, while the best ventilation prevailed, thirty-four cases of sickness, or eight per month, were treated by the medical officer; while after the latter date, thirteen cases were treated in 12 days.

If carbonic acid is an essential element in causing compressed-air sickness, it would seem that, taken in conjunction with the other contributing causes, a partial explanation of the ailment is afforded by the assumption of a large absorption of the gas by the human system, and a subsequent effect due to that absorption. As carbonic acid gas is readily absorbed by liquids—in water to the extent of about 66 per cent. by volume at atmospheric pressure —the blood under the compressed air may become highly charged with it: so that on reducing the pressure the expanding gas may discharge into joints and tissues and even into the circulation channels, causing painful inflations or mechanical obstruction to the ordinary flow.

The remedies applied by the medical officer were re-compression followed by slow de-compression, the administration of the drug ergot, and sometimes the application of liniments. In almost every case re-compression in the medical lock afforded relief from pain; and slow de-compression usually seemed an effective remedy.

Every provision for the workers in the compressed air was made by the contractors, Messrs. Perry and Co. Hot coffee was served to them on leaving work; dry working-clothes were provided,

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and a changing-room for going to work and leaving under suitable healthy conditions. There were no deaths; and although two men were provided for after the compressed-air work in consequence of serious illness, one of them, finding outside work not paying so well as mining, returned to tunnel-work, and is anxious to work again in compressed air, to which, in fact, his illness was not due.

The East Tunnel.

As the depth of the surface of the clay at the places where the tunnels enter and leave the ballast had been verified by the first tunnelling, and the nature of the ballast had been learned; and as the adaptation of the shield, the machinery and the general appliances had been tested, and the general conditions ascertained; it was a simpler matter to arrange the commencement of the east tunnel with certainty of results than it had been for the west tunnel. After the shield emerged from the ballast, in the construction of the west tunnel, some months were required for it to complete its journey to Waterloo. Small alterations were then effected in it, before re-erecting for the east tunnel. By cutting away the forward flange of the box-girder, and also the front of the vertical girder, and the front ends of the hood gussets, a few inches more working-room was obtained for the miners; so that the work could be brought altogether under cover of the hood. It had been necessary in the west tunnel to set forward the face-timbers some inches beyond the cutting edge of the shield, whereas the alteration obviated this. Figs. 11, Plate 3, show the mode of working adopted in the east tunnel.

The pattern of iron casting was also slightly altered at the joints, with the object of getting spaces that could be more easily caulked and a better body of material for permanent effectiveness. It has been found that the new joints shown in Figs. 9, Plate 2, and the rings put together with wooden packing-slips, tapered from $\frac{5}{8}$ inch at the back of the iron to $\frac{1}{2}$ inch at the interior of the flange, cut widely clear of the bolts, are the most suitable. The interior face of the packings in place is chiselled out to a depth of $\frac{3}{4}$ inch, and the space can then be securely caulked.

The east tunnel was begun from the temporary shaft at the river-stage on the 17th May, 1901. The air-tight diaphragm-wall, with air-locks, pipes, etc., was erected 100 feet from the shaft; and the use of compressed-air was begun on the 24th June with still about 9 feet of clay cover over the shield. The box heading was continued until the ballast was reached on the 27th June with an

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auger-boring from the length in front of the shield. The tunnel touched the ballast on the 6th July, and a full face of ballast was encountered on the 1st August. The air-pressure employed was the exact equivalent of the head of water in the river above the invert at the face; on the 1st August it was 27 lbs. per square inch at high water, and 18 lbs. per square inch at low water.

Many of the miners who began this tunnel had had the experience of the one previously constructed. They had learned that to adhere closely to the details of working as directed by the engineers was the surest method of ensuring rapid progress; and that the warnings against blows were not without necessity. Blows, they found, could occur; and piece-work with steady progress paid best. The consequence of this was that, with more careful attention to the clay-pugging process and to the security of the face and retention of the air, the compressed-air work proceeded regularly, expeditiously, and economically with a full face of ballast, which varied from time to time from very open material to fine close sand, often in layers of the same face. The rate of progress was more than 5 lineal feet per working-day of three 8-hour shifts; and the weekly progress has reached 36 feet.

The success of this work has shown incontestably that the method of tunnelling employed, with the use of the clay pocket and the hooded shield, as devised by Mr. Dalrymple-Hay, is admirably adapted to the Thames water-bearing ballast.

The east tunnel again encountered the London clay at the invert on the 26th September; and the shield completed its work through the ballast on the 2nd October, 1901, when a full face of London clay was again obtained. The amount of compressed-air driven into this tunnel has been on the average 100,000 cubic feet per hour, measured at atmospheric pressure, during the full face of ballast.

The Engineers were Sir Benjamin Baker, K.C.M.G., Past-President Inst. C.E., and Messrs. Galbraith and Church, MM. Inst. C.E. Mr. H. H. Dalrymple-Hay, M. Inst. C.E., was Chief Assistant to Messrs. Galbraith and Church. Mr. C. A. Rowell, as Contractors' agent for Messrs. Perry & Co., carried the work through. The Author was Resident Engineer.

The Paper is accompanied by sixteen drawings, from which Plates 2 and 3 have been prepared.

[APPENDIX.

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APPENDIX.

Particulars of Machinery.

Boilers—

Two 100-N.HP. marine (Laird).

Three 40-N.HP. locomotive type (Davey, Paxman & Co., and Nicholson & Co.).

One 80-N.HP. semi-marine (Davey, Paxman & Co.).

Air-Compressors—

Three double-acting, for 60 revolutions at 100 lbs. steam-pressure.
Steam-cylinders 18 inches in diameter × 30 inches stroke.
Air-cylinders 26 inches in diameter × 30 inches stroke.
Water-jacketed. (Markham & Co., Chesterfield.)

One portable, for grouting-pans (Slee & Co., Earlestown).

Dynamos—

Two (Thomas Parker), worked by Belliss engines on the same frame :— 600 revolutions, 130 amperes at 210 volts; 27 kilowatts; for locomotive traction.

Two similar to above but giving 62 amperes; 13 kilowatts; for electric light.

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Discussion.

The PRESIDENT moved a vote of thanks to the Authors for their interesting Papers, which was accorded unanimously. The President.

Mr. H. H. BARTLETT remarked that it had been thought before the Baker Street and Waterloo Railway tunnelling was commenced that a revolving cutting shield might be used in the water-bearing strata; and Mr. Rowell, who had so ably carried out the work, had designed such a shield working on ball-bearings. It would have answered its purpose; but higher authorities at that time had thought the experiment rather too risky, and therefore the method described in the Paper had been adopted. At first he had been rather anxious, as there were apparently no medical or other reports to guide him as to the danger incurred by the men in that class of work. He had felt that was a want which ought to be met, and he had therefore taken means to obtain medical aid, through the late Dr. Bond, who had recommended a very able man for the post. That medical man had been in constant attendance at the works. Mr. Bartlett had desired that some definite rules might be drawn up for the treatment of men suffering from compressed air, which might form a guide for other works also, and prevent not only loss of life, but suffering. The results had been satisfactory and had justified the arrangements made. The work had been carried through successfully, and very few accidents —none of them serious—had occurred. Mr. Bartlett.

Dr. A. H. MACMORRAN desired to make a few remarks from a physiological and pathological point of view, of interest both to engineers and to medical men. One thing that had struck him was that in the Paper on the Baker Street and Waterloo Railway the amount of carbonic acid found by analysis was stated at as low a figure as 0·07 to 0·08 per cent., being only 0·1 per cent. even with a clay face. In the Greenwich subway, with which he had had to do, there had been found in the shield as much as 0·19 or 0·21 per cent. of carbonic acid; and it had shocked him to think that men should work in an atmosphere containing so much of that gas. Fortunately, Mr. Copperthwaite had contrived, by means of a blow-out pipe carried forward to the shield, to get rid of a large amount of the carbonic acid; and it would be Dr. Macmorran.

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Dr. Macmoran.

seen from the Paper that the percentage had been reduced in one case from 0·18 to 0·124 per cent., and in another case from 0·125 to 0·09 per cent. That result was much more favourable than the result secured by the adoption of the scrubbers containing caustic soda. This latter plan, however, should not be criticized too severely, because the device had been installed when the tunnel was under construction, and therefore its value could not be properly judged. If such purifiers were included in the plant when it was being laid down, he believed much better results could be obtained. In the second Paper there was a suggestion to which he must demur, namely, that under compressed air the carbonic acid was contained in the blood in excess; and that when the pressure was taken off the blood discharged its carbonic acid into the tissues of the joints and the muscles, thus causing pain. He also objected to the division of the symptoms of the ailment known as compressed-air disease into mechanical and pathological; because if it were the case that the blood did so discharge its carbonic acid, then surely that was mechanical pressure. It seemed to him that the only symptom that could be purely mechanical was the buzzing in the ears and deafness which occurred on having the pressure raised in the air-lock. The bleeding from the nose and the pain behind the ears were as much pathological as mechanical. Considering the subject from a common-sense point of view, it was much more likely that the disease was due to irritation of the centres in the brain than to irritation of the nerves at the periphery. It had been stated that compressed air had no effect upon the circulation as regarded pressure upon the skin; but he considered that a pressure of 24 lbs. to 28 lbs. per square inch upon the human body must decidedly diminish the blood in the capillaries of the skin. Such blood must go to the deeper and better protected vessels, which were situated to a large extent in the skull, as the skull resisted pressure most. The veins were likely to be over-distended, as the arteries had the direct pressure of the heart behind them; therefore the blood became sluggish in the larger veins, which were better protected. If that was granted, it was more in accordance with common sense to consider that the cause of compressed-air disease was the slow circulation of the blood, and more impure blood, around the centres of the brain that governed the whole of the functions of the body. That would lead to poisoning, no matter whether there was carbonic acid in the blood or any other poisonous gas. He thought there was an analogy with compressed-air disease to be found. The impurities that

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remained in the blood of a person suffering from kidney-disease gave rise to severe nerve pains all over the body, quite akin to the pains in compressed-air disease: there was also coma and twitching: but then it was not due to carbonic acid, but to urea. He held that carbonic acid was not the only gas in the blood, but that the breathing of compressed air impeded the elimination from the blood of all the excess impurities of the body. Given a man who had a perfectly healthy liver and kidneys, which also removed the impurities from the body, the compressed air would not affect him if his lungs were able to discharge continually as much carbonic acid as was necessary in order to keep him in good health while working. The severe work that the men did caused immense waste in the body; and were it not that they perspired freely and frequently the effects of compressed-air work would be much more serious than they actually were. If it was desired to keep men in a healthy state working at a pressure of 24 lbs. to 28 lbs. per square inch, they must be given as pure a supply of air as possible; they must be physically perfect; and they must be subjected to air-pressure for as short a time as possible, and the shorter the time the better. Under extra high pressure the shifts should be made shorter still. In other words, there should be rigorous rejection of the unfit, and continuous and thorough sifting of those already passed, having regard both to their habits of eating and drinking and to their health on going into the compressed air. Under these conditions there would be much less compressed-air disease. Dr. Macmorran.

Dr. G. Severs, as the medical officer to the Baker Street and Waterloo Railway during the second crossing of the river, remarked that in that time there had been twenty-one cases of illness directly due to compressed air, and of those twelve had been so severe as to need treatment by re-compression in the medical air-lock. With regard to the cause of this interesting and mysterious disease, he quite agreed with Mr. Haigh that the three main factors were the intensity of the pressure, the proportion of carbonic acid present in the air and the length of stay in the medium. The fourth cause mentioned by Mr. Copperthwaite, namely, a limited supply of air, he was inclined to classify under "proportion of carbonic acid." But, in his opinion, there was another important factor, which was the amount of water to which the men were exposed in the tunnel. He was led to that conclusion by the following facts. As Mr. Haigh stated in his Paper, the compressed air had been used from the 24th June to the 20th October, a period of 119 days. During that time Dr. Severs.

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Dr. Severs. the face of the tunnel had consisted of clay for 30 days, and of water-bearing strata for 89 days. The percentage of carbonic acid, which he had determined by Pettenkofer's process at frequent intervals during the whole time, had varied between 0·05 per cent. and 0·08 per cent. while the face was of gravel, and between 0·09 per cent. and 0·13 per cent. while the face was of clay. From those figures, the length of stay in the air being the same and the difference in pressure very small, more cases, and cases of greater severity, would naturally be expected while working in the clay than when in the water-bearing strata. But the reverse had happened. With a full face of clay there had been only one case of illness, and that not severe enough to require re-compression—that was, one case in 30 days; but in the water-bearing strata there had been twenty cases, twelve of which had been very severe; which was at the rate of one case in 4½ days. As bearing out that conclusion, it might be mentioned that one of the most severe cases had been that of a man who, before leaving the compressed air, had had a bucket of water thrown over him by a fellow-workman as a joke. Another bad case had occurred in a man who on leaving the tunnel had gone home, a distance of 3 miles, on top of an omnibus, and had got wet through. Another fact which helped to support that theory was that on the construction of the Central London Railway, where compressed air had been used for several months, there had been, he understood, very few cases of compressed-air illness, and those cases not severe. There the pressure had varied between 15 lbs. and 20 lbs. per square inch; and he had been told that only 2,000 cubic feet of fresh air per man per hour had been supplied, as against 5,000 cubic feet on the Baker Street and Waterloo Railway. But there had been a full face of clay, except for a short time at Shepherd's Bush, where the tunnels were in gravel; the working-pressure, however, had been only 5 lbs. per square inch. When working in clay the men were not standing in water as they were in gravel. There was no doubt that medical men had in front of them a large amount of patient work and investigation before they could say that their knowledge of compressed-air illness rested upon a satisfactory scientific basis.

Mr. Dalrymple-Hay. Mr. H. H. DALRYMPLE-HAY remarked that he took the greatest possible interest in the shield system of tunnelling, as it was now eight years since he started such work. When he had been first introduced to that mode of tunnelling he had been in absolute ignorance of what had been done previously, and in that state he had taken up the appointment of resident

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engineer on the Waterloo and City Railway, on Mr. Galbraith's advice, and under that gentleman and the late Mr. J. H. Greathead. Like many other people, he had been a little disappointed in seeing what went on in front of the ordinary Greathead shield when it had reached the ballast; the method of timbering in front of the shield had not been at all to his liking, and the system had struck him as not being the shield system of tunnelling. He had suggested to Mr. Galbraith that there were other ways of doing the work, and the method which had struck him as being the proper one to adopt when in water-bearing gravel was to form pockets of clay around the cutting edge, as described in Mr. Haigh's Paper. He was somewhat surprised to see Mr. Copperthwaite's statement that the system had been devised by Brunel, or by his miners, because when he devised the system he had really been quite ignorant that anything of the same nature had been done before. He had referred to the only work he could find describing Brunel's great Thames tunnel, and that was the late Mr. Henry Law's account of it;[1] and he frankly confessed that there were points of similarity between the system which had been carried out at Rotherhithe and the system carried out in the Baker Street and Waterloo tunnel, which, he claimed, had been adopted for the first time on the Waterloo and City Railway. He had found it stated in Mr. Law's account of the Thames Tunnel that where the material had been very hard—he did not quite know what that meant—and where there had been coarse gravel, the ground had been excavated in front of the shield to the extent of 6 inches as a maximum, but generally to 3 inches, because the ground had been, as a rule, rather bad, and in bad ground the distance had been only about 3 inches. In the Waterloo and Baker Street tunnel at Charing Cross the ground had been exceptionally bad; in fact, he thought anybody who had had anything to do with work of that kind would admit it was quite as bad as anything that had been found at Rotherhithe. He could not find anywhere in Mr. Law's account of the Thames Tunnel that the excavation had been taken more than 6 inches ahead, and those who were familiar with the system of tunnelling carried out at Charing Cross would agree that there was a wide difference between forming an excavation only 3 inches, or even 6 inches, in advance of the shield, as Brunel had done, and the method carried out in the Baker Street and Waterloo Railway tunnels of forming an excavation of 23 inches—about eight times the distance adopted by

Mr. Dalrymple Hay.

[1] "Operation and Construction of the Thames Tunnel." London, 1857.

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Mr. Dalrymple-Hay. Brunel in the worst kind of material. What Brunel had done in front of his shield appeared to be no more than what was ordinarily done when constructing a timbered heading. He had himself worked in a timbered heading on the Waterloo and City Railway, and instead of driving the piles forward in the manner generally understood by "driving a pile," the ground had been first removed by scraping it away in front of the piles, and a hole had then been formed. In order to keep this hole from being closed in by the ground, it had to be filled at once with straw and clay, and then the piles were tapped forward. In the Rotherhithe tunnel similar holes had been made, but there had been no piles; what were called "staves" had been used—horizontal plates, which were not tapped but screwed forward. That, however, was not the essential difference between Brunel's method and the method adopted on the Waterloo and City and Baker Street and Waterloo Railways. What had been done in those two instances, and what Brunel had not done, was to deliberately excavate pot-holes not only 23 inches long, but extending 2 inches or 3 inches above or outside the shield; so that not only was the entire cutting edge completely buried in the tempered clay when the shield advanced, but there was a skin or layer of tempered clay left behind the shield as it advanced, where the ground lost the support of the tail of the shield. As far as he could make out from the drawings of the Greenwich tunnel, the pot-holes had not been made above the shield so as to leave a layer of tempered clay behind. The object of making the pot-holes in the particular way described in Mr. Haigh's paper was threefold; first, that the compressed air might be locked in and not escape at the tail with each advance of the shield, as was the case with every other known system; secondly, that the ground left unsupported by the last advance of the shield might be supported by the elastic force of the compressed air in the tunnel; lastly—and not the least important object—to enable the annular space between the outside of the tunnel and the ground to be filled with lime grout so as to avoid subsidence of the ground overhead. That certainly could not have been done by Brunel; for the Thames Tunnel had not been constructed under compressed air, although during the 17 years' progress of the work Lord Cochrane had invented the compressed-air system, and Brunel had had at that time the same means of doing the work that engineers now possessed.

Mr. Galbraith. Mr. Wm. R. Galbraith thought a point had now been reached in the construction of subaqueous tunnels, beyond which there was

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little likelihood of further advance. The trap system of shield, with two diaphragms, afforded to the men working in the tunnels under compressed air that protection which had been so much desired; and, there being security to give the men confidence in their work, he did not see that any important improvement was likely to take place in the method. No fatal accidents had occurred from blows in a tunnel since the two diaphragms, with the compressed air acting upon the water between them, had been used. In what he had to say about the shield he referred to compressed-air working, because driving a shield in the London clay was so thoroughly understood, and now worked so well, that there was little to be said about it, and little improvement in it to be looked for. No doubt by the aid of machinery it might be possible to drive more rapidly; but that was merely a matter of improvements in the machinery—a question of whether all the work should be done by hand-labour, or whether the excavation could be done by machinery, the clay being excavated and delivered behind the shield, without having recourse to so much manual labour. He desired to say a few words upon the hooded shield, and the driving of the hood into the clay. According to Mr. Copperthwaite, that was the system adopted by Brunel, but he thought there must be some misapprehension on the point; at all events, when he had been associated with Mr. Greathead on the Waterloo and City line, he had naturally deferred to Mr. Greathead's greater experience in such work, and had been rather taken aback on seeing the method adopted, namely, practically forming a timber tunnel and driving forward the shield underneath it. If not hazardous during construction, that appeared to entail future risk; because a time might come when the timber would perish, and no doubt considerable cavities would be left which might lead to trouble later. Mr. Dalrymple-Hay had suggested a method of forming an annular space, about 18 inches in depth, and driving the shield into it, whereby no timber whatever was left above the shield; and when Mr. Hay had consulted him on the subject it had seemed to him a new idea, and on his advice Mr. Hay had taken out a patent for it. Mr. Hay had been assured by a patent agent that the idea was a new one, and therefore one which might be maintained. He was sorry to say it had not led to much profit for Mr. Hay, because some of the wealthier employers had resisted the matter, and, of course, a resident engineer was not a man with a purse long enough to engage in a legal contest with a powerful body. He thought, however, it was right to say that he considered the invention of Mr. Dalrymple-Hay was an exceedingly

Mr. Galbraith.

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Mr. Galbraith. valuable one, which had been highly successful on the Baker Street and Waterloo line under the river. In that work there had been a head of water of 70 feet at spring tides, filtering through pure gravel, and when the men had become accustomed to the work the second tunnel had been carried out without a single hitch or accident, and more rapidly than the first tunnel. He ventured to think that Mr. Hay's idea was novel and his system an excellent one. It differed from the system which had been carried out formerly. At the Greenwich tunnel the clay seemed to have been carried only to the top of the shield; whereas in Mr. Hay's system the shield was driven into the clay, and the work was absolutely sealed. There might be differences of opinion as to the date of the invention, and as to whether Mr. Hay was really the inventor or not; but he would like to claim in the Institution some merit for a young engineer who had given his whole heart to the work, and whose system had been carried out so successfully in tunnels in the London clay and under the River Thames. He also wished to bear testimony to the wonderful accuracy with which the setting out of the underground lines had been done under difficult circumstances. Mr. Haigh would say something about the setting out of the Baker Street and Waterloo line, and therefore he would not do more than contrast the rough-and-ready methods of 55 years ago, to which his recollection went back, with the extraordinary accuracy of the present day. The Baker Street and Waterloo tunnel had started at one end from a shaft in the river, and at the other end from a shaft in Piccadilly; and the centre lines of the two tunnels had met in the Haymarket within about $\frac{3}{4}$ inch or less—a result which appeared to him to reflect great credit on the rising generation. Other examples could be mentioned, but that one illustration would serve. In conclusion, he wished to bear testimony to the highly satisfactory manner in which the tunnel under the river had been carried out by the contractors, Messrs. Perry and Company, and by their excellent agent, Mr. Rowell. The quality of the work was very good, the tunnels had been beautifully driven, and the greatest credit was due to Messrs. Perry and their staff, and to Mr. Haigh for the excellent manner in which he had supervised the work. The Chairman of the London and South Western Railway Company, in conversation before a general meeting, had asked him what he was to say to the shareholders about the Waterloo and City Railway, and Mr. Galbraith had replied that he might tell the shareholders something about the shield—that a shield

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had been dropped into the river somewhere near Blackfriars Bridge, and in due time had appeared exactly at its place near Waterloo. He felt proud of the young engineers for the skilful way in which they carried out such work. A great deal was heard of the consulting engineers and the head men; but those who were in charge of the work ought to have testimony given to them, and the heads of departments ought certainly to express the appreciation they felt of their work. He had not seen what Mr. Copperthwaite had done, but he was quite sure from what he knew of that gentleman in other matters, in connection with the Central London Railway, that his work had been of equal excellence. People were becoming so accustomed to seeing a shield erected in a shaft on one side of the river, driven through the river, and brought exactly into a corresponding shaft on the other side of the river, that they did not think anything of it; but the accuracy of the feat was wonderful. As Engineer to the Baker Street and Waterloo Railway he wished to express his appreciation of the work of his assistants and contractors, and he was sure Sir Alexander Binnie would bear equal testimony to the way in which Mr. Copperthwaite had carried out his work. Mr. Galbraith

Mr. J. N. SHOOLBRED observed that it might be interesting to compare the work described in the Papers with some previous work under compressed air where he had the opportunity of seeing the effects, namely, at the Forth Bridge, about 20 years ago. He had been engaged by the contractors for that bridge to lay down the arrangements for the electric light. The lighting and other applications of electricity had been required not only on the surface, but in various other places, among them the caissons which formed the foundations of the piers. Not only had the lighting to be done, but, by means of the same dynamo, the blasting of the rock had been effected; and the lighting and blasting had been carried on simultaneously without any interference with, or disturbance of, the electric light by the blasting. The working-pressure had generally been about 28 lbs. to 35 lbs. per square inch above atmospheric pressure, according to the rise of the tide, which was about 18 feet at ordinary tides, and as much as 22 feet at equinoctials. The working-chamber forming the bottom of the caisson had been about 70 feet in diameter and about 9 feet high. He drew particular attention to that, because he thought any ill-effects arising from compressed air were much modified in a chamber of that character, compared with the small confined spaces such as divers worked in, or a horizontal tube 12 feet in diameter such as the Greenwich tunnel. No ill-effects Mr. Shoolbred

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Mr. Shoolbred. whatever had been perceived at the Forth Bridge from the pressure of the compressed air. The divers, who had had considerable previous experience on similar work at Antwerp, had worked a 4-hour shift, and had generally tried to put in two shifts in the 24 hours. After a certain time the ill-effect of this prolonged working had manifested itself upon the divers in a sort of gradual paralysis. The cure had been to send the men to the dynamo-room to get a number of electric shocks at the ordinary voltage of 120 volts, and with a considerable strength of current. However, the treatment had had the desired effect, and after a time the men had gone back to work apparently cured. He understood that in the work under discussion the effects had been more serious, and of the usual kind, namely, bleeding at the eyes, nose or mouth. That had not taken place at the Forth Bridge, due probably to the larger working-chamber; although apparently the pressure under which the men had worked there was nearly equal to the maximum pressure mentioned in the Papers. At present attention seemed to be drawn to the curative properties of the electric current much more than had been the case hitherto, and it appeared to him the main factor in producing more favourable results was the larger quantity of current used at lower voltage. Possibly the facts he had mentioned might elicit a little more information with regard to the results noticed in the course of the interesting works described in the Papers.

Mr. Moir. Mr. E. W. MOIR remarked that Mr. Copperthwaite drew attention to the fact that if the ballast for the purpose of sinking the caisson was put upon the lower instead of the upper floor level it would make a considerable difference to the righting moment; but he mentioned that only 900 tons of ballast had been used altogether, and that the caisson had tilted only some 6 inches. Mr. Moir was of opinion that such a small inclination would not materially alter the righting effect of the ballast, even if at the higher level. The lower floor was mentioned as being more expensive, because it involved an extra few feet in depth of caisson, which added to the expense of the shaft if two floors were used. Not only was there the extra depth to pay for, but there was the additional weight of structural material in the second floor. The fact that the concrete added no dead weight to the floor to resist the upward air-pressure was another disadvantage. In the Blackwall caissons there had been no lower floor equal to carrying the upward water-pressure, but a very light structure instead, below the concrete; and every ounce of concrete above had formed part of the resistance to keep the floor in its place.

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As a consequence it had been only ¼ inch thick. It had been very satisfactory, and there had been practically no leak through it on removing the air-pressure. Thus there had been a saving of 4 feet in depth of caisson and the weight of a lower floor, and all the concrete had been doing useful work. There were some advantages no doubt in putting a second floor at the bottom, but they had to be carefully weighed, taking into consideration the facts he had mentioned. Mr. Copperthwaite stated, in regard to the resistance of the floor to the upward pressure of the air, that there was a pressure of about 300 tons on the flanges of the girders at their ends, but he presumed 300 tons shearing stress on the end was meant, as he could not conceive how there could be anything like 300 tons flange-load at the girder-ends. In the design of the Blackwall caissons the same difficulty had been experienced which Mr. Copperthwaite had found, namely, in transmitting the heavy reaction from the girders to the thin skin. At Blackwall doubling plates upon the inner shells had had to be used so as to make the upward load produce such a small beam stress on the inner shell that the vertical deflection was practically nothing, and the load was distributed around a great length of seam, thereby bringing into play a sufficient number of rivets to take up the load. The reaction had been something like 400 tons, and he would be glad to know whether it was the reaction Mr. Copperthwaite referred to or the boom load. In the interesting Table given at p. 8 the skin-friction on the caisson was shown to amount to 3·8 cwt. per square foot, but elsewhere in the Paper a gross dead weight of 2,560 tons was mentioned; such dead weight would indicate a skin-friction reaching 6 cwt. per square foot. No doubt something had to be deducted on account of the air-pressure under the floor, and the Author seemed to have deducted the gross amount, or about 20 lbs. per square inch all over the floor, but at the same time stated that, in order to sink the caisson, the air-pressure had been reduced. He would be glad to know how much the air-pressure had been lowered, and what the actual skin-friction had been at the maximum depth, as the figure indicated in the Table was unusually small. In fact, on one of the large caissons at Blackwall, the one with which the greatest trouble had been experienced, it had risen at one time to 10 cwt. per square foot; but there the Thanet sand had had to be dealt with and some other very sticky material, including green sandy clay. The use of the clay-pocket system around the cutting edge, on which some remarks had been made, seemed to him to be a novelty. At Blackwall clay

Mr. Moir.

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Mr. Moir. had been blown into and smeared upon the face, and an immense quantity of clay had been put into the river-bed; and practically the same result had been arrived at as Mr. Dalrymple-Hay had achieved, the gravel running out underneath and the clay coming on to the shield from above, where it had been dug out in large quantities. A patent had also been taken out to cover the possibility of forcing clay over the lining into the grouting space at the back of the shield, and Mr. Hay's operation seemed to embody the same idea, namely, a skin of clay that would hold up the ballast and prevent the escape of air. He did not think, however, that in large shields, say 27 feet or 30 feet in diameter, with a ballast face, he would like to be the man, if there were only 5 feet of gravel between him and the river-bed, as at Blackwall, to go outside and put pockets of clay around and in front of the shield cutting edge. It required considerable care to retain the air if only small holes, 7 inches by 3 inches, were opened. So great was the turmoil caused by the escaping air that the flints flashed fire, like an old flint and steel, even among water; and he certainly would not advocate, with a very thin covering of gravel, any attempt to go boldly up to the cutting edge and begin to tackle the gravel in the way it could be done in tunnels of small diameter where the air-pressure would dry the whole face. In fact, he was sure the run into the shield would be so enormous that there would be a blow through to the river-bed before it could be stopped. At Blackwall, with a 15-foot blanket of clay, it had not mattered how much the gravel ran in, as there had been ample clay to take its place. He certainly did not think Brunel had ever had any intention of systematically mining all round the top of his shield for the purpose of excavating gravel, and replacing the same with clay. When tenders had been invited for the Greenwich subway, the specification had called for 8,000 cubic feet of air per man per hour. At that time he had expressed, in the Institution, a belief that such a quantity was not necessary; and inasmuch as it cost about 2*d.* per thousand cubic feet to produce even in very large quantities, and much more on a small scale, it made a considerable difference in the wages-bill. He was glad to see that the London County Council had relaxed their requirements, and had allowed the contractor to work with 4,000 to 5,000 cubic feet per man per hour, which must have been a considerable benefit to him and was quite safe for the men. The analyses of air proved that any such quantity as 8,000 cubic feet hourly was not necessary. An ordinary man at rest respired something like 0·7 to 0·8 cubic foot per hour of carbonic acid gas, and inasmuch as

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anything below one part in a thousand at the pressures used was not detrimental, if 3,000 cubic feet was given per man, and it were assumed that when at work the man produced twice the quantity of CO_2 that he would at rest, the proportion was only brought up to 0·7 part per thousand as the ultimate impurity of the air, allowing that the air contained 0·4 part per thousand on the earth's surface. It had been proved repeatedly by systematic analyses that this was not a dangerous amount of CO_2 up to 25 lbs. per square inch above atmospheric pressure. He was glad to see that some effort had been made towards removing the carbonic acid from the air before it was passed to the men in the tunnel. No doubt ultimately that would be done when very high air-pressures were required for certain deep-water works. In 1896, in a Paper[1] read before the Society of Arts, he had advocated such a system, and he was sure that for very high pressures the carbonic acid would be removed or reduced to a minimum before the air was supplied to the men, with beneficial results. Some results had been achieved by the process that had been tried, and, although it was an expensive thing to do, it would pay in the long run for high pressures. He did not think, however, it was necessary up to 35 lbs. or 40 lbs. per square inch, provided that an ample supply of air was delivered to the men and the percentage of carbonic acid was kept low. At the Hudson tunnel, 12 years ago, when riveting up a shield under a pressure of 40 lbs. per square inch above atmospheric pressure, there had been a rivet-fire 2,000 feet from the shaft, having a funnel 2,000 feet long and 2½ inches in diameter. According to the analysis there had been as much as 2 per cent. of carbonic acid and 2 per cent. of carbonic oxide in the air, that was, 20 parts per thousand. The men had died at the rate of 25 per cent. per annum, and nobody had seemed to care anything about it. In New Jersey there were no inquests; and so the work had gone merrily on until a method of reducing the ill-effects had been stumbled on by him. This was done by introducing a compressed-air chamber, which had proved a great success, and of which he had already spoken in the Institution. No doubt impurities that could easily be dealt with by the human system under ordinary atmospheric pressure became very deadly under high air-pressure when that air-pressure was suddenly reduced (as in passing out through an air-look). When discussing the point with him some years ago, Dr. Haldane, of Oxford, who had made a great many experiments on impure air and air mixed with other gases, had told him of an experiment he had made

Mr. Moir.

[1] Journal of the Society of Arts, vol. xliv. p. 567.

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Mr. Moir. with a mouse. The animal had been immersed under pressure in an atmosphere containing a high percentage of carbonic oxide, and had run round inside a glass globe perfectly happy while the pressure was maintained, but on a sudden reduction of the pressure to that of the atmosphere the mouse had died at once. That was precisely what was found in compressed-air work when the air became foul. The men were quite fit inside, but if they came out suddenly or even, as customary, in a few minutes, within about ½ hour or ¾ hour thereafter they had pains or collapsed. According to the experience gained at the Hudson tunnel, re-immersion always cured them; and that he thought was a proof that the cause of the disease was largely mechanical. A previous speaker—a medical man—had stated that he did not believe there was anything mechanical about the disease, but Mr. Moir thought this was a mistake. If a man, although unconscious and dying, when re-immersed sat up and looked round within a very few minutes, and came out in half an hour quite recovered, it was obvious there must be some mechanical cause. No chemical change could take place in such a short time, and there was very little doubt that the disease was due to the absorption of carbonic acid by the blood, as he had always contended. There was a story told of some people who had been finishing a tunnel, and had been anxious to emphasize their pleasure by taking in and drinking a bottle of champagne under compressed air. They had been very disappointed to find the champagne exceedingly flat when opened, and they had drunk it; but the effect when they came out of that compressed air could be imagined. He thought the blood was in somewhat the same condition as that champagne.

Mr. Fitz-maurice. Mr. MAURICE FITZMAURICE remarked that, knowing the two tunnels to be very similar, he had hoped it would be possible to draw some interesting comparisons between the two Papers; and that the Authors might have introduced some individual variations in the method of carrying out the work, and explained their reasons for so doing: in fact, he had been almost sanguine enough to expect to find in one Paper the criticism of the other. But on reading the Papers he had not found that such variations in the method of working had occurred. Except for the bold head-line which informed the reader that he was shunted off the Greenwich tunnel on to the Baker Street and Waterloo Railway, it might almost be imagined that the Papers described the same work, and had been written by the same Author. Not only were the tunnels the same, but the method of working was the same, the shields were much the same, and the rate of progress was identical. He knew it was difficult in the Institution to

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get an account of the cost of any work; but he supposed that if the cost per yard of the two tunnels under consideration were known, it would be found to be the same to the last halfpenny. He did not make those remarks in order to depreciate the work which had been done by the Authors in any way; on the contrary, he thought difficult work had been carried out in a satisfactory manner, and at a very good rate of progress. What he did infer was practically what Mr. Galbraith had remarked, namely, that the time appeared to have come when there was not much room for further individual invention, or for further variation, in the method of driving small tunnels through gravel charged with water. Engineers who had been accustomed to driving tunnels through London clay, now appeared to start that work with the same confidence as they would start the building of a house. That remark, however, evidently would not apply to the cost. It had been his duty during the past few weeks to go into the question of the cost of various tunnels, and he had found that in four "tube" railways recently promoted, on the same route, the capital cost per mile varied between £450,000 and £1,000,000, which was a very considerable variation. It might be that some engineers had underestimated, and others had overestimated; or it might be that speculators in "tubes" were not content with the same profit as speculators in houses. He hoped that, after these Papers, engineers would be able to attack the construction of small tunnels through gravel with the same confidence with which they already dealt with tunnels in the London clay. He particularly meant his remarks to refer to small tunnels only, because in tunnels of large diameter, where there was a great difference of hydrostatic head at top and bottom of the tunnel, there were many difficulties to be met. He did not agree with Mr. Moir that it was better to have a single floor in the caisson, because he thought the second air-tight floor at the bottom had many advantages. The concrete there could do its work just as well as if that floor did not exist, and the lower floor certainly bound the whole caisson much better together, and was better in regard to water-tightness when the job was finished. He had had a great deal to do with the sinking of large caissons, both with and without second floors, and he believed that the lower floor was of considerable advantage. The question of the batter of caissons had been practically thrashed out, and the general conclusion was that it was better to make them with very little or no batter. With reference to the timbered face of tunnels, he much preferred, if possible, to work with iron shutters, because when the

Mr. Fitzmaurice.

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Mr. Fitzmaurice.

shield was pushed forward the timber was so much broken up that there was a large escape of air. He could understand, however, that in small tunnels there might be considerable difficulty in using the iron shutter. He would be glad if Mr. Copperthwaite could give some estimate of the cost of freeing the air from carbonic acid by the method he had suggested. Although that method had been in use only for a short time, and was more or less a crude one, probably the Author had been able to estimate what the cost would be on a larger scale. With regard to the use of clay, he thought the fact of the clay coming round to the back of the shield and making an air-tight seal was an excellent thing, but he did not quite understand how it improved grouting behind the cast-iron lining, because he would imagine that the clay came down so quickly that the grout could not get forced in. Although the clay might not have been used in exactly the same way, he thought clay had been used to a large extent, and more or less in that way, in some cases. Recently he had looked up a report to the London County Council about 13 years ago, on the St. Clair tunnel, made by Sir Benjamin Baker, after an inspection of that work. In his report Sir Benjamin stated that a certain amount of soft clay had been filled into the pockets of the shield, and held there by the pressure of the air against the working-face of the gravel; and he went on to say that the excavation had been carried on through the clay. The method appeared to be very similar to what had been done in the tunnels under discussion, although in the case of the St. Clair tunnel nothing was said about the clay forming an air-seal at the back of the shield. He agreed with Mr. Dalrymple-Hay in regard to making the shield do its own work, and not timbering a space in front, as had been done on the City and South London Railway, because that was simply building a tunnel and putting the shield into it. That instance was really exceptional in shield driving; the practice had certainly not been adopted by Brunel, or at the St. Clair tunnel. He had been rather surprised to hear Mr. Bartlett say that he had been unable to find any published information about work under compressed air, because the London County Council had gone to considerable expense at Blackwall, and had had a doctor living over the tunnel for several years, gathering all possible information on the subject. That gentleman, Dr. E. H. Snell, had published a valuable book on the subject,[1] which would be very useful to any one who was carrying out work of that kind. With

[1] "Compressed-air Illness." London, 1896.

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regard to the quantity of air which Mr. Moir had objected to in the London County Council's specification, he could not hold out any hope that the amount specified would be reduced. Mr. Moir, he was sure, would understand that it was not always possible to get exactly what was specified. If 8,000 cubic feet was aimed at, it might be possible to get 6,000 cubic feet; it was better to keep to the upper limit in the hope of attaining as near to it as possible. It was very satisfactory that in the case of both tunnels under discussion doctors had been employed to look after the men working in compressed air, and he was sure the men quite appreciated the employer's interest in them. Under Sir Alexander Binnie, at the beginning of the Greenwich tunnel works, he had been responsible for a good deal of the design, and, in fact, he believed he had been the resident engineer for about 24 hours. It was a great pleasure to him to see that the work had been so thoroughly well carried out by Mr. Copperthwaite, and the contractors, Messrs. Cochrane, and to read the excellent description given of it. Mr. Fitzmaurice.

Mr. F. E. WENTWORTH-SHEILDS remarked that, although there were several points of similarity in the construction of the two tunnels, he thought there were one or two points of difference which suggested interesting comparisons. For instance, there was the skin-friction of the cylinders or caissons. In the Baker Street and Waterloo cylinders the skin-friction had been 2½ cwt. per square foot, which certainly seemed exceedingly moderate; but he supposed that was partly accounted for by the fact that a large portion of the cylinder had been practically in soft mud, and that only a fraction of it had been in the London clay. In this connection he might mention that at Oxford Circus a shaft had been sunk about 40 feet into the ballast, with a skin-friction of less than 1 cwt. per square foot, a figure which he thought would be difficult to beat. He attributed that result largely to the fact that the cylinder had retained its shape exceedingly well, and had also been kept very upright, a point which was doubtless of much importance in cylinder-sinking. Also, perhaps, partly to the effect of a rather interesting experiment tried at the suggestion of Mr. Dalrymple-Hay, namely, forming a pocket below the cutting edge, and inserting pugged clay, precisely as in the shield described in Mr. Haigh's Paper, only, of course, the movement had been vertical instead of horizontal. He could not say that the smallness of the skin-friction had been entirely due to that cause, because the clay-stopping system had not been used round the whole length of the rim, but only along a portion of it, to see whether the idea Mr. Wentworth-Sheilds

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Mr. Wentworth-Sheilds.

was practicable. It had been found to give fair results; and although the clay had been dragged down a little, still, it had been quite possible, at all events in dry ballast, to sink in that way. He believed the method would probably have the advantage of diminishing the skin-friction in certain cases, and of assisting largely in holding up the earth securely behind the cylinder. Again, in the Greenwich tunnel the segments were bonded, while in the Baker Street tunnel they were not. The engineers of the Baker Street and Waterloo Railway were, he believed, quite alive to the advantages of bonding, but they had come to the conclusion that it had one serious disadvantage, namely, that if by any chance the bolt-holes should not be accurately spaced, it might happen that at one of the longitudinal joints the plates would not quite meet. A point in favour of bonding was that it was possible thereby to keep the tunnel much more truly circular. For instance, in a tunnel driven by hand, where there was no shield-tail to act as a mould for erecting the rings, the workmen had to be trusted to erect the tunnel as a true circle. If no bonding was employed the circle sometimes became a bad ellipse; whereas with bonding it was impossible for the workmen to erect the tunnel in any but a circular form. Another interesting point about the works under consideration, although not a point of difference, was that in both cases shutters had been tried and abandoned; and it would be interesting to hear the opinions of some engineers who had used shutters, and had perhaps a good word to say for them. His own opinion was that there might yet be cases where the shutters would come into use. Looking at the longitudinal section of the Baker Street and Waterloo Railway tunnel, it would be seen that Mr. Haigh had had to drive his shield through a stratum which was almost as bad as it could be. There had been a bed of nothing but ballast between the roof of the tunnel and the river. Of course such a bed would allow the air to escape very freely: but a worse case might be imagined. Mr. Haigh stated that the air-spaces in his ballast amounted to between one-fourth and one-third of the bulk of the ballast, say, 30 per cent. of it. He had made some experiments at Southampton, and had found that a ballast which was fairly sandy—a suitable ballast for concrete—contained about 31 per cent. of air-spaces. Another ballast, a rough sample but still by no means free from sand, he had found to contain about 38 per cent. of air-spaces. Supposing that a tunnel had to be driven through such ballast as that, under the same difficulties as Mr. Haigh had had to contend

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with, namely, with nothing but ballast between the roof of the tunnel and the water, the air would escape much more freely than it had escaped in the tunnel under discussion. Consequently with the slightest opening made in the tunnel for excavation, even supposing that the clay-stopping system was used—which would of course be done after the experience that had been obtained—blows would be almost sure to occur. If the face was timbered and blows did occur, the timber would probably be dislocated. Mr. Haigh described two blows, and thought the cause of one of them had been lack of vertical support through the strutting timbers not being sufficiently inclined; but if there was any serious run of water and ballast into the face, however much the struts were inclined, they would not prevent the ballast getting loosened behind, and once that happened down would come the timbers. Shutters would have the advantage that when that dislocation took place, provided they were fixed by screws or other means, they would stay in place, whereas timbers would not. It would be said that with shutters the plastering of the face with clay which had been done on those two works could not be so easily carried out. Probably that was so, especially at the top of the shield. In order to set back the top part of the face, and smear it over with pugged clay, it would be necessary to take away the shutter or timber altogether; and in order to take it away it was necessary to have something light, which meant timber. But lower down he did not see why the iron shutters should not be retained, because as the work progressed downward it would be easy to draw back the shutter a little way, and to excavate the ballast behind it, setting forward the new face, smearing it with clay, and then pushing the shutter into its new position. That was, of course, assuming a shutter could be designed which could easily be moved forward, and which would not suffer, as the shutters had suffered on the Baker Street and Waterloo Railway works, from rough handling by the workmen. He commended to builders of shields the idea of designing a shield with shutters worked by small rams instead of screws, which would be quicker in action, and not so liable to be strained out of shape. Whether they would be too bulky to work he could not say, not having had the experience. With regard to compressed air, it was quite consoling to know, after what Mr. Moir had said, that a compressed-air tunnel could now be built without so much disease and death as had formerly occurred. Medical officers now said that the system of working was by no means dangerous under proper conditions. According to Mr.

Mr. Wentworth-Sheilds.

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Mr. Wentworth-Sheilds. Copperthwaite, Dr. Macmorran had even found that compressed air was good for the heart. One speaker had raised an interesting point about the difference between working in a place like a tunnel and working in a diver's dress or a confined space. At the Admiralty harbour works at Dover men were working in diving dress in something like 65 feet of water, which would mean a pressure of about 30 lbs. per square inch: and it would be interesting to hear what was the effect on the men of working under those conditions.

Sir A. Binnie. Sir ALEXANDER BINNIE remarked that the two Papers under discussion, with the Paper by Messrs. Hay and Fitzmaurice on the Blackwall tunnel, would be found to give a fair summary of the modern mode of constructing tunnels through water-bearing strata by means of compressed air. When in 1890 Sir Benjamin Baker and he had had to advise the London County Council as to the possibility of constructing a tunnel at Blackwall through that large bed of gravel, previous experience had had to be looked to—the experience gained at the Hudson tunnel and at the St. Clair tunnel, and on other compressed-air work in the United States; and undoubtedly the outlook had been neither promising nor agreeable to any engineer who was called upon to take the responsibility of advising on a work of that description. Owing to the lessons which had been learned, engineers had now arrived at a stage when they could carry on such work with perfect safety and with due regard to economy of both life and labour. The many ingenious devices suggested in these three Papers were indicative of the desire which every engineer had to improve the methods of working. One thing, if he might be excused for saying so, he deprecated exceedingly, and that was the attempt to take out patents for small details of work—not for such great inventions as the Bessemer process, but for minor details—and without having taken the trouble to look at the literature of the profession. For instance, the idea of the shield, which had been referred to so freely in the discussion—a circular wrought-iron shield—was found embalmed in the specifications of Brunel, although he had been unable to use a shield of that description. Compressed air had also been patented about the same time by Lord Cochrane. In reading the literature of that time a little misapprehension had arisen about the hood to which Mr. Galbraith had alluded. Brunel had not used for the Rotherhithe tunnel the shield patented by him, presumably because the mechanical appliances of those days had not been sufficiently advanced to

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make it practicable; but he had used a shield of very ingenious construction, composed of a series of compartments, sliding one over the other. It was conceivable, from some of the existing descriptions of the use of that shield, that the upper chambers might have been thrust forward over the lower chambers; not to any large extent probably, but still to an extent which would have the effect of producing what might be called the hood-arrangement which all who had worked in that kind of ground earnestly desired to obtain. Another matter fairly well settled, notwithstanding what had been said that evening, was that in the sinking of the shafts or caissons it was possible to adopt the principle so successfully used at the Forth Bridge, and to carry the excavation-chamber to the lowest possible point in the shaft. At the Blackwall tunnel he had originally specified that as the mode in which the work should be carried out, but unfortunately he had yielded, perhaps somewhat too weakly, to the desire of Sir Weetman Pearson, the contractor, and had allowed him to carry on the excavation by means of an air-tight floor placed above the crown of the tunnel: and he had always regretted having done so. It could be seen at once what must happen. The lower part of such a caisson, for a depth of 30 feet or 35 feet, was filled with compressed air of considerable buoyancy. The top of the caisson might be loaded, but the centre of gravity was thereby raised to a considerable height above the cutting edge. With the excavation-chamber at the bottom of the shaft, the centre of gravity was lowered to the lowest possible point, and consequently much more control over the cylinder was obtained than in any other way with which he was acquainted. Another thing which was admitted universally was that the outside of the shaft should be as nearly cylindrical as possible. Turning from the actual modes of construction, which were exceedingly interesting, to some other matters which had been learned, he desired to say a few words as to the River Thames. To engineers and others who had to do with that great water-way of the largest city in the world it was always an interesting river. How did that river come into existence? Was it caused by some great fault? Something had been revealed by the three tunnels at Blackwall, Greenwich and Charing Cross, which enabled those questions to be answered at once and decidedly. Neither at Blackwall nor at Greenwich nor at Charing Cross was there the slightest sign of any fault along the Thames valley. Therefore it must be assumed that the valley was the result of denudation, and some interesting facts came out with regard to that point. It would be

Sir A. Binnie.

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Sir A. Binnie. remembered that at Blackwall, just above the embouchure of the River Lea, the river flowed on its north side by Poplar and to the south were the Greenwich marshes. At that point the bottom of the great gravel bed through which the Blackwall tunnel had had to be driven had never been reached; but the point which had been reached, namely, the junction of the gravel with the true geological strata, was 95 feet below Ordnance datum. That meant that at some period there must have been a great river, the bottom of which was 95 feet below the present mean sea-level. At Charing Cross the north side of the Thames was the higher, and southward was the great marsh which had formerly extended from Battersea to Deptford, and had no doubt been to a large extent the old course of the River Thames. At that point the depth below Ordnance datum was about 84 feet. At the Greenwich tunnel he did not think the old bed of the Thames had been reached at all; he thought it probably passed along the line of what was now the West India Docks; but even at that point the gravel, where it joined the Woolwich and Reading beds, was 40 feet below Ordnance datum. Therefore the Thames had to be looked upon as a great valley of denudation which had been filled up in the course of ages during the gradual subsidence of the whole area of the Thames valley. It was an exceedingly interesting question; and those who had to deal with the estuary of the Thames should bear in mind that the existing river was but a puny representative, both in breadth and in depth, of the great river which in geological ages must have flowed down the Thames valley.

Sir F. Bramwell. Sir FREDERICK BRAMWELL, Bart., Past-President, in reference to Sir Alexander Binnie's observations that in the original Thames tunnel, which had been made by means of a shield in compartments, the upper compartments might have moved forward relatively to the lower, remarked that he supposed he was one of the few persons now living who had been taken into that shield by the elder Brunel. He had therefore seen the compartments, and he felt quite certain that they had been dealt with in the manner Sir Alexander Binnie had suggested, namely, by independent movement. He believed there had been four horizontal rows of twelve in a row.

Dr. Brightmore. Dr. A. W. BRIGHTMORE remarked that, having been resident engineer for Mr. G. F. Deacon on the Mersey aqueduct tunnel, which had been referred to, he had been struck by one point of difference between the driving of that tunnel and the tunnels under consideration. In the Mersey tunnel it had not been found

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possible to maintain the air-pressure in the tunnel equal to the static pressure of the water outside; in fact, the pressure in the tunnel had generally been about 5 lbs. per square inch less than the static pressure of the water at that level; with the result that a certain amount of water at those times had flowed into the tunnel: and he concluded that the water had flowed in at such a rate that the resistance it met with in its flow had been equal to the difference between the static pressure of water at that depth and that of the air inside. In fact, the strata in that case had been in the same position as the filtering material in an ordinary filter-bed. The difference in the head of water at the outlet-well and over the sand represented the pressure necessary to force the water through the filtering material. It seemed to him that in this case the conditions were practically the same—with an increased thickness of filtering material. In the cases under discussion he understood that the pressure had been generally rather greater than the static head at low water, and he attributed that to the fact that since the air was flowing out from the tunnel and holding the water back a certain distance, the pressure of air in the tunnel would be the static head of the water plus the friction of the air in flowing from the tunnel to the point to which the water was driven back in a horizontal direction. The other point to which he wished to refer was the rotation of the shield. It had been found in the Mersey aqueduct tunnel, and in most other tunnels driven with shields, that there was a tendency for the shield to rotate slightly as it advanced. It had been impossible to check that tendency at the Mersey aqueduct tunnel by means of the leverage of a 30-foot rail on which pressure had been applied in order to try to prevent the shield rotating. The only explanation of that rotation seemed to be that the axis of one or more of the hydraulic rams was slightly out of line with the axis of the shield, which would cause the shield to rotate; he believed it always rotated in the same direction, which confirmed this view.

Dr. Brightmore.

Mr. G. GONSALVES thought that in Papers read before the Institution sufficient credit was not always given to the contractors' agents and engineers looking after the work. They not only had to satisfy the engineers of the works, but also their employers who supplied the money, and they had to make the work a financial success. He was sure that the agents on the two works under consideration must have had an anxious and responsible time while the works were in progress. The first thing that had struck him was the great difference in power necessary to drive

Mr. Gonsalves.

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Mr. Gonsalves. the two shields. In the Greenwich tunnel the total power was 750 tons, whereas in the Baker Street and Waterloo Railway tunnel it was only 160 tons. The two shields were of about the same diameter, but one was 5 feet longer than the other. Would that make all the difference stated in the Papers in the power required to drive the shields forward? The longer shield of the Greenwich tunnel required nearly five times the power of the Baker Street and Waterloo tunnel shield. He also wished to ask whether there had been any difficulty, when the shield went from a level to an incline, in getting it to take the altered direction. It would be of great interest if some engineer who had been engaged in setting out lines under the streets of London would indicate exactly how the work was done. Mr. Haigh had mentioned how it had been done across the river, but it would be interesting to know the method adopted for the tunnels under the streets of London. They must be set out with very great accuracy when one tunnel had to meet another.

Mr. Brown. Mr. JAMES BROWN remarked that Mr. Copperthwaite advocated vertical sides to the caissons and an air-tight floor as near to the cutting edge of the shaft as possible. He quite agreed with the latter point, and he believed the accuracy with which the shafts had been sunk was mainly due to the fact of the air-tight floor being so low; but he was not so sure about the vertical sides. The Table in the Paper (p. 8) referred to the Poplar shaft only, and while the Greenwich shaft had been sunk with similar regularity, after it entered the shelly clay it had become very difficult to move, and that difficulty had increased the lower the shaft was sunk. So long as it had been in sand and ballast the skin-friction had worked out much the same as at the Poplar shaft, namely, 4 cwt. to 4½ cwt. per square foot; but after entering the shelly clay it had risen to 6 cwt. per square foot of surface, and when within 1 foot of the bottom to 8 cwt. At the last attempt to sink, with only 2 inches farther to go, the load had been increased to 8·17 cwt. per square foot, and then the shaft had declined to move. Therefore he thought possibly the caissons might have been better with a slight taper on the outer skin, or perhaps a mistake had been made in discontinuing the use of the lubricating-pipes. These pipes had been fitted on the Poplar shaft, but they had not been required there, as the shaft had sunk freely in the soft sand, and they had been used only occasionally, more by way of experiment than anything else—Mr. Copperthwaite said, "without appreciable results." He had been very sceptical himself about deriving any benefit from their use, as he had expected that the

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compressed air escaping round the cutting edge of the shaft would merely force back the water into the ground and leave the skin dry. But he had calculated the skin-friction for the first day on which the pipes had been in use, when presumably they had been in perfect working-order, and he had obtained a better result on that day than on any other occasion. On the 22nd May, before fitting the pipes, the skin-friction had been 4·26 cwt. per square foot. On the 24th May, when the pipes had been first used, the skin-friction had fallen to 3·61 cwt.; and on the 30th May, after discontinuing the use of the pipes, it had risen again to 3·94 cwt. The pipes seemed therefore to have had quite a considerable effect; but as the water had been drawn from the river-bed the pipes had soon become choked and useless, and it had been decided not to fit them on the Greenwich shaft. With regard to the tunnel-lining, Mr. Copperthwaite claimed that the lead washers used to fill up the countersunk holes under the heads and nuts of bolts were highly successful in stopping any leakage. He agreed that they were successful, but still such slight leakage as there was came through the bolt-holes; either because sufficient lead to quite fill the hole had not been used in every case, or possibly because there had been a slight movement after the bolts had been tightened up, causing the joint between the lead and the iron to be broken; and as there was no elasticity in the lead, a slight space might have been left through which water could find its way. He believed still better results would have been obtained by using a flax or hemp grommet under the lead, fitting tightly on the neck of the bolt. It was noteworthy that in the first nineteen rings of the tunnel, where grommets had been used and not lead washers, there was no leakage at all; but of course that was in the highest part of the tunnel where there was the least hydrostatic pressure. The leakage, however, was so slight that Mr. Copperthwaite's claim was quite justified. When the air-pressure had first been taken off, between 40 gallons and 60 gallons of water per hour had penetrated into the tunnel; but the quantity had now been reduced to 12 or 15 gallons; and he thought that would compare favourably with any subaqueous tunnel in existence. Mr. Copperthwaite said little about the plant, and there was not really much of a novel kind; but one feature of the installation to which he wished to call attention was the pneumatic riveting-plant. About 115,000 rivets had been put into the two caissons, and wherever possible they had been put in by pneumatic machines, 60 per cent. of the whole work being done by Boyer pistols. The pistols closed the

Mr. Brown.

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Mr. Brown. rivets, $\frac{7}{8}$-inch in diameter, with perfect ease and finish, upsetting the rivets in the holes much better than did the ordinary hand-riveting; and on the whole they gave more satisfactory results, provided that the pressure was maintained at 90 lbs. or 100 lbs. per square inch. Any faulty rivets were found to have been put in when the pressure had fallen below that amount. The pressure had been supplied by an Ingersoll-Sergeant straight-line piston-inlet air-compressor of about 40 I.HP., with an automatic unloading regulator; and the same engine, besides supplying pressure for the riveters, had supplied air for blowing rivet-forges and a smith's forge, for working a lathe in the fitters' shop, and the pneumatic drill. Later, it had driven a duplex haulage-engine, hung in the roof of the tunnel just inside the air-lock, for winding skips up the incline, and, through a reducing-valve, had supplied compressed air for grouting. Later still, it had worked a small pump in the tunnel. The question of compressed air as affecting workmen had already been discussed from the medical point of view, and he had not much to say on the matter; but owing, he believed, to the large supply of fresh air and to the care exercised by Dr. Macmorran in examining the men—particularly after holidays—there had been hardly any cases of compressed-air illness; fewer than had occurred in any other tunnel with which he had been connected. In fact, Dr. Macmorran's principal complaint had been that he could not get cases. The experiments carried out in the endeavour to purify the air were very interesting, and considering the crude apparatus which had had to be used, he thought the results were satisfactory. Mr. Copperthwaite's suggestion at the end of his Paper, that arrangements should be made in the installation for a device for purifying the air by scrubbers or some other method, was, he believed, quite feasible. If the carbonic acid gas could be eliminated from the air, or greatly reduced, not only would the workmen be benefited, but considerable economy in the cost of the work would also result; for a much smaller volume of air would be required, and therefore smaller compressors and less boiler-power would be needed, with a consequent reduction in the coal-bill. A new method of purifying air had been brought to his notice a few days ago. It was an apparatus called an oxygen-regenerator, and he believed it had been successfully tested in Paris. Sodium dioxide in contact with water was decomposed and gave off oxygen, sodium hydroxide remaining, which immediately absorbed any carbonic acid gas present, forming sodium carbonate. The apparatus depending on those reactions continually renewed

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the oxygen of the atmosphere and at the same time used up the carbonic acid gas that might be formed. He did not know that the apparatus had been designed for use in compressed-air tunnelling, but he saw no reasons why it should not be so used. As had been remarked by a previous speaker, the presentation of the two Papers together offered opportunities for some interesting comparisons, both as to the design and the method of execution of the works. The first point that struck him was the wide difference in the thickness and weight of the cast-iron lining of the tunnels. The two tunnels were almost exactly of the same diameter, at the same depth below water-level, and in similar strata; yet the thickness of metal in one case was 1 inch against $1\frac{1}{4}$ inch in the other, with a depth of flange of $4\frac{7}{8}$ inches in the former against 6 inches in the latter. The length of the ring in the Baker Street and Waterloo tunnel was only 18 inches, against 20 inches in the Greenwich tunnel; still, the former weighed 3 tons 10 cwt. 3 qrs. per yard against 4 tons 2 cwt. 2 qrs. in the case of the Greenwich tunnel, a difference of 12 cwt., which meant about £8 or £10 per lineal yard of tunnel. On the Waterloo and City Railway, with an external diameter of 13 feet, the depth to the top of the tunnel was 50 feet, the length of ring 20 inches, and the weight 3 tons 2 cwt. per lineal yard. On the Baker Street and Waterloo Railway, with almost exactly the same diameter, namely, 12 feet $9\frac{3}{4}$ inches, a rather greater depth, 60 feet, and length of ring 18 inches, the weight was 3 tons $10\frac{1}{2}$ cwt. per yard. The external diameter of the Greenwich Footway Tunnel was 12 feet 9 inches, depth to top 53 feet, length of ring 20 inches, and weight per yard 4 tons $2\frac{1}{2}$ cwt. On the Mersey aqueduct tunnel, with an external diameter of 10 feet, depth to top about 52 feet, length of ring 18 inches, the weight per lineal yard was almost exactly the same as that of the Greenwich tunnel, namely, 4 tons 2 cwt. He did not suppose it was quite possible to standardize the "tubes," but he did not understand why there should be such wide differences. Variations in the design of the shield were perhaps more to be expected, and for some reasons he preferred the Baker Street and Waterloo shield to the one used at Greenwich, principally because it was shorter and much lighter, and therefore more easily handled, especially on curves. He noticed that it had been driven round a 12-chain curve. The Greenwich shield had been driven round two vertical curves of the same radius, but not without considerable difficulty owing to its length and weight. Originally designed by Mr. Cochrane, the shield had been made both longer and heavier by the addition, at the desire of the Engineer to the

Mr. Brown.

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Mr. Brown. London County Council, of the annular girder shown in front of the diaphragm, and by thickening the skin-plates. In one of the County Council's own tunnels under the River Lea, the shield for which had been designed shortly after, he had noticed that the annular girder was altogether dispensed with, and he was of opinion that it could have been done without at Greenwich also. At the same time, it was but right to state that the shield had done its work without in the least losing shape; and on arriving at the Greenwich shaft after tunnelling under the river it had been absolutely undeformed and undamaged. The trap seemed to have acted satisfactorily in both shields. At Greenwich it had proved absolutely effective in stopping any blows that occurred; and not an ounce of sand or other material had got through the shield into the tunnel. The worst blow had brought about 8 cubic yards into the shield and had delayed progress about 1½ hour. He did not quite like the solid diaphragm on the top part of the Baker Street and Waterloo shield. It appeared to him to offer but little chance of escape to the men should they be working in the top at the moment of a serious inrush, especially when it was considered that when the men started in the top to break forward, the shield was forced close up against the timbered face and there was very little room for them to get through. He was glad to hear the men had always escaped, but he thought Mr. Cochrane's method of providing an egress through the top diaphragm was safer and to be preferred. With regard to the hood, the short projecting hood of Mr. Dalrymple-Hay's shield was well conceived to overcome some of the difficulties in that class of tunnelling, but he thought it led into another. At Greenwich it had been found that almost all the blows originated in the haunches, just where Mr. Hay cut away the bottom of his shield and left the invert unprotected; and it was just there that a loss of pressure was first felt when working in bad ground. Mr. Haigh stated that in ballast the pressure was equal to the hydraulic head of tidal water, but Mr. Brown had never found it so. At Greenwich, when working in ballast at high water, a pressure of between 3 lbs. and 5 lbs. per square inch less than the pressure equal to the hydraulic head had been quite sufficient to keep the face dry; but the curious thing about it had been that it had not been possible to reduce the pressure to correspond with the fall in the tide; so that at low water the pressure had been 1 lb. to 3 lbs. per square inch higher than the theoretical figure. His principals had been so dubious about that fact that a slight blow had been actually started in trying to reduce the pressure to equal the hydraulic head.

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In the soft sand it had been found possible to reduce the pressure to correspond with the rise and fall of the tide, and always to keep it below the theoretical figure. Mr. Brown.

Mr. COPPERTHWAITE, in reply, remarked that in both tunnels the engineers had been fortunate in having had no experience whatever of really bad cases of compressed-air disease. The cases at Greenwich, at all events, had been almost all entirely due to the men's own fault. The men were taken care of; they were made to come out at the breakfast hours and were provided with hot coffee, hot water, and proper bathing-places: then they went out and drank two or three pints of cold beer, with the result that they became unwell. They attributed it to compressed air, but the majority of the cases were due to cold beer. As to the attempt to remove the carbonic acid, the experimental plant which had been used was very crude. A sensible diminution in the amount of carbonic acid in the air had been found after taking it into use—the air had been fresher; and the fact that the pumice-stone which carried the caustic-soda solution had become coated with carbonate of soda was other evidence that a certain amount of carbonic acid had actually been removed. The method had been carried out for only about two months, and although it had been done in a very crude manner, boys carrying in the caustic soda by hand, it had cost roughly £1 per day, including material, but not including the cost of the first plant. Mr. Bartlett had mentioned that he had contemplated at one time having a revolving shield. Mr. Copperthwaite had had to deal with small tunnels for some time, and had seen two mechanical excavators at work. When the mechanical excavator was at work it did well; but it worked for a day and then lay idle for a week. On the Central London Railway, both Messrs. Scott, the contractors for the division of which he had been in charge, and Messrs. Price, on Mr. Binnie's division, had spent much money and considerable time and care in making experiments, but without success. The mechanical excavator had been tried in Berlin and in Paris, and in both cases it had never got beyond the model stage. He believed Mr. Greathead had tried one, and had had a model made: he was not sure that gentleman had not had a shield made in the days of the City and South London line, but it had never been tested by actual work. If a piece of machinery of that kind was put into a small shield and a breakdown occurred the working-space was filled to such an extent that it was necessary to strip the shield before it was possible to go on with the work. In a larger tunnel that difficulty did not arise, and he thought it was quite possible, in Mr. Copperthwaite.

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Mr. Copperthwaite.

a large tunnel like the Blackwall tunnel, to use a portable excavator that might do good work. With regard to Mr. Bartlett's difficulty in procuring medical reports as to the conditions of working in compressed air, the account of the Blackwall tunnel in Dr. Snell's work[1] was very complete, and contained a great deal of information; and there was a book[2] by a Frenchman, Mr. Paul Bert, an exhaustive treatise on the physiological effects of working in compressed air, which all engineers engaged in such work ought to consult. Then, of course, there was the classic case of the St. Louis Bridge, the first place where any real observations had been made[3]; and there was a full account of work under compressed air in Drinker's work on tunnelling.[4] As to the working of the shield, he thought Mr. Galbraith and himself were practically in agreement. It appeared to him that Mr. Dalrymple-Hay had hit upon a new idea in making the clay pass over the outside of the shield and close the opening at the tail end. He thought he had read about the method of working every known shield, and he did not think that had been done before; it was a new idea, and it certainly kept the air in at the back of the shield. At Greenwich that method had not been used: it had not been thought of, and even if it had been thought of, it could not have been used, because the Greenwich shield had been fitted with twenty-six teeth on the circumference, and it would have been quite impossible to excavate behind those teeth in such a way as to form a complete clay ring for the shield to work in. In fact, it had not been necessary. The teeth had been used because such teeth had done good service in the case of the Mersey tunnel. It was stated in connection with that work that the pressure required to drive the shield forward before the teeth were put on had been 4,000 lbs. per square inch, and that after the teeth were put on the pressure had been reduced to 2,000 lbs. per square inch. At Greenwich the teeth had worked highly satisfactorily. With regard to the hood and digging out the pocket in front of the shield, the idea of which Mr. Hay stated had occurred to him, it was a good idea, but hardly a novel one. The hooded shield had been patented in England, in France, and in Germany, and he thought it had been patented also in the United States: at all events, a hooded shield had been made

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[1] *Ante*, p. 58.

[2] "La Pression Barométrique: Recherches de Physiologie Expérimentale." Paris, 1878.

[3] C. M. Woodward. "A History of the St. Louis Bridge, &c." St. Louis, 1881.

[4] H. S. Drinker. "Tunneling, Explosive Compounds and Rock Drills." 3rd edition. New York, 1893.

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there in connection with the works of a gas company. He was bound to say that Mr. Hay's shield was more satisfactory in appearance than any of the others. He was not a great admirer of the hooded shield, and he thought Mr. Hay's was quite harmless, though many hooded shields were not. He thought a hood like that shown in Figs. 3, Plate 2, forming a comparatively small portion of the shield, might do good work, as Mr. Haigh said it had done. With regard to the clay in front of the shield, the explanation in Mr. Law's description of Brunel's tunnel was clear, but he did not quite follow Mr. Hay in the statement that there was a difference between his method and Brunel's because Brunel's shield had only advanced 3 inches to 6 inches at a time, whereas the other advanced 23 inches. Mr. Hay's shield advanced 23 inches because the stroke of his rams was that distance; in the Greenwich tunnel the shield had advanced 11 inches because that had been the practice there: and Brunel's shield had advanced 3 inches to 6 inches because it had been his practice to go forward only that distance. Exactly the same arrangement had been used at the St. Clair tunnel. But he thought the carrying of the clay over the top of the tunnel, when it could be done, would prove very effective in retaining the air, and it should also assist in keeping up the ground above. The opinion had been expressed that tunnel-work had reached finality. He thought it probable that there was as much machinery and as many obstructions now put into a shield as could possibly be worked with. There was really far too much, and he looked forward to seeing a shield without any plates in it at all, but having at the rear the two safety diaphragms placed in such a way that they could be moved at the end of each day's work. Something of the kind could be done, and would greatly diminish the cost of the shield; and he did not see that it would increase the risk to the work. The length of the shield at Greenwich had been due to the following circumstance. In the original design, instead of hydraulic rams, there had been sliding tables extending right across the horizontal diameter of the shield, and consequently the length of the shield had been increased by the length of the box in which each ram was moved —about 4 feet. Otherwise the shield would not have differed much in size from Mr. Haigh's shield. As to the setting-out, on which Mr. Galbraith had kindly complimented the younger generation of engineers, he remembered a case on the Central London Railway in which Mr. Brown, the contractor's engineer at Greenwich, and he had been interested. In constructing the line between the Bank and the Post Office stations, they had started with a shield

Mr. Copperthwaite.

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Mr. Copperthwaite.

at each end, and had met near Bow Church. The contractor's men in the shield, by dint of a little humouring of the rings and a little stretching, made the two tunnels meet so exactly that the bolts had fitted in, and the two tunnels had been bolted up; and any one looking at the tunnel at that spot would see it was continuous, and had no break in it at all. Mr. Moir, who had had long experience of such works, doubted if the additional floor in sinking the shaft was worth the extra trouble and expense. He had determined the exact position of the centre of gravity of the shaft at Greenwich with the kentledge placed on the lower floor, and also with the kentledge placed on the top floor; and he found that, using the lower floor, the centre of gravity of the whole mass was 10 feet—nearly 11 feet in fact—lower than it would have been if the kentledge had been put at the top. That was a highly important point in a shaft only 60 feet deep, and it practically meant that when working the weight was always well below the centre of gravity of the shaft. How "tickle" such shafts were, no one knew who had not sunk them. He thought Mr. Brown might be correct in his opinion that the success of sinking the shaft had been due as much to having the weight at the bottom as to having the side perfectly vertical. In reply to Mr. Moir's question about the girders of the floors, they were not shown on the drawing, but the floor was composed of two pairs of girders crossing each other at right angles. If the girders were tightly riveted up where they crossed each other, the stress would be much less than the figure given in the Paper; but he thought, for safety, it was advisable to assume that two of the girders were through girders, extending from side to side of the shaft, and that they had no support at all from cross bracing. If they were considered as two girders, about 34 feet long, with thin, continuous webs, the stress at each flange would be just over 300 tons. With regard to the skin-friction, the Table (p. 8), was perhaps hardly definite enough. One column of the Table gave the pressure, and another the skin-friction at various dates; but, of course, he did not mean that the pressure given in the column had been the pressure exactly at the moment when the skin-friction had been taken. Supposing the pressure to have been 16 lbs. per square inch, and the excavation to have been taken out to the extent shown in Fig. 4, Plate 1, the custom had been to lower the pressure gently, and a drop of about 4 lbs. per square inch in the pressure had generally been found enough to make the shaft bury the cutting edge in the sand: it was on those figures that the skin-friction had been worked out.

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Mr. Copperthwaite.

As to the danger of working in shields of that type with only 5 feet of ballast over the top, he thought the danger lay not so much in the 5 feet of ballast as in the vertical diameter of the shield. A large tunnel with water at 5 feet over the top would be hazardous to work in; but in a small tunnel, where the hydraulic head at different points of the face varied so little, he did not think there would be any danger at all. As to the quantity of air supplied to the men, a point on which Mr. Moir had remarked that although 8,000 cubic feet of air per hour had been specified, 5,000 cubic feet had been accepted, he thought he could mention instances in which contractors had made tunnels for the London County Council, and had not even come as near to the specification as that. Warm thanks were due to Mr. Moir, because he had done more than any one else in introducing the medical lock; and if there was one point on which engineers were agreed, it was that the medical lock was a restorative. Mr. Fitzmaurice had remarked upon the resemblance between the two tunnels, and the equality of the rate of progress. He understood that at Charing Cross three rings, of a total length of 5 feet, had been erected per day regularly, and at Greenwich the progress had been exactly the same when working in ballast; but in the close sand under the middle of the river the high speed of 10 feet per day had been attained from the 22nd February to the 1st May, and it had not mattered whether a man or two was absent or not; the men had managed to put in two rings every shift. Mr. Brown had some doubt as to whether the want of batter was an entirely satisfactory feature of the shaft. He did not quite follow Mr. Brown, because from Fig. 2, Plate 1, it would be seen that the shelly clay which Mr. Brown considered was the cause of the evil was so near the bottom that it would not matter whether the shaft had a batter or not. The real explanation of the Greenwich shaft sticking, which was apparently due to high skin-friction, was that the two top rings of the shaft had been a little out of truth, one diameter being a couple of inches larger than the other, so that at one point the shaft had been actually wedge-shaped, and had had to be forced down. In reply to Mr. Wentworth-Sheilds's questions about breaking joint, no trouble had been found at all in making the joints bed together properly. The bolt-holes had about $\frac{1}{4}$ inch play, and the bolts were large. In the whole length of tunnel there were about 12,000 lineal yards of caulked joints, and but little money had been spent upon them. There was no open space at all. To Mr. Sheilds's suggestion that it would be a good idea to have shutters,

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Mr. Copperthwaite. he thought the same objection would apply as applied to so many other things in small shields, namely, that there was so much machinery and material in them already that it was difficult to find working-space for the men. He considered the tendency would be to simplify the shield and to put the safeguards farther back in the tunnel. With regard to rotation of shields, all shields rotated, probably owing, as Mr. Brightmore had remarked, to the fact that the axis of the ram was not quite parallel to the axis of the shield. When working in the shelly clay at Greenwich, an endeavour had been made in fairly safe strata to fix two inclined knives on the outside of the shield, in order to see if the rotation could thereby be counteracted; but the shield had continued to twist just the same. As to the thickness of the cast metal in the tunnel, the tunnel was very solid, but he did not think it was too heavy. At the time the thicknesses were settled it had not been decided to break joint, that decision having been come to later. By breaking joint the metal could have been made a little lighter; but bearing in mind an occurrence on the City and South London Railway, he did not think any one was justified in cutting down the cast metal. Not more than two years ago, one of the castings on that line had broken, fortunately at night, when no trains had been running. He thought there ought to be a large margin of safety under a river. As to the pneumatic riveters, he considered them good tools. The hand-pistols were quite satisfactory up to $\frac{7}{8}$ inch in diameter, providing the air-pressure was kept up to 100 lbs. per square inch. The men would rather have something lighter, but if the pressure was 100 lbs. per square inch, and the $\frac{7}{8}$-inch rivets were not put through too many plates, the hand-pistols answered very well indeed.

Mr. Haigh. Mr. HAIGH, in reply, observed that the east tunnel had been under construction through the ballast at the time the Paper was written, and its completion had enabled a short summary of its progress to be inserted. The complete description referred to the west tunnel, which had been more serious in the matter of water-pressure, and, having been the first under construction, had been more experimental in the mode of execution. The second tunnel had required an air-pressure of 5 lbs. per square inch less than had had to be adopted in the first tunnel, and the medical results were sufficiently remarkable to show the great difference which variation of pressure made in the miners' liability to "bends." As had been mentioned by Dr. Severs, only twenty-one cases had been treated during the whole of the driving of the east tunnel, as against forty-seven by Dr. Wainwright in the other tunnel.

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Mr. Haigh

Of those twenty-one cases, seven had not been clearly attributable to "bends," but had been slight illnesses, the origin of which was not at all certain. They had occurred in the early part of the work, and might have been due to the men's physical unfitness to stand the pressure. The amount of air driven through had been practically the same in the second tunnel as in the first, and the proportion of carbon dioxide measured had varied between 0·06 per cent. and 0·13 per cent., according to the amount of compressed air delivered. But the results did not altogether bear out some conclusions which might have been drawn from the earlier experience, because twelve of the cases of "bends" had occurred with a full face of ballast, leaving only two serious cases when the face had been wholly or partially clay and the air had contained a larger charge of carbonic acid. As one altogether without medical knowledge, he had suggested to the medical officer at the commencement of the earlier work that the state of the weather and the temperature had a great deal to do with the miners being subject to attacks of "bends." During the hottest weather the temperature in the compressed air did not exceed the temperature in the open; whereas in colder weather the temperature in the compressed air was greatly in excess of that outside. The fact that attacks always occurred some considerable time after exposure to the ordinary atmosphere might also suggest that the change of conditions in this respect on coming into the open had something to do with it. Whether the affection was at the limbs or at the cerebral end of the extensors he must leave medical skill to determine. He had had no experience of the application of electric currents to the curing of "bends," as mentioned by Mr. Shoolbred. At the Forth Bridge 4-hour shifts had been adopted under high pressures, which had reached 37 lbs. per square inch in the caissons, as against 8-hour shifts for the Baker Street and Waterloo work. As to the behaviour of the shield itself, notwithstanding some previous experience of the hooded shield, and the general opinion which seemed to be held that there would be some tendency to dip at the nose and dive downwards, there had not been the least tendency of that kind manifested. The upward pressure against the hood with air at 30 lbs. per square inch, would give a leverage about the bottom front edge of 40 foot-tons, which was a considerable help towards keeping up the shield. The special arrangement of the rams shown in Fig. 3, Plate 2, whereby the pressure was concentrated at the bottom of the shield, had been adopted in order to accomplish that very object, and to avoid the anticipated dipping of the shield. The object had

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Mr. Haigh. been achieved; for neither in the ballast nor in the clay had there been any tendency for the shield to dip. In the clay the shield had generally been working with piles against the top of the face bringing down the material; but on approaching the ballast the piles had not been used, and still there had been no trouble from the shield moving downward. It was quite evident that with the power of driving concentrated so low down, the moment of that force was not so great about a point at the bottom as it would be with higher arms. There had also been no tendency to rotation such as had been referred to by several speakers. The greatest departure from the horizontal of the edge of the back plate of the fountain trap had not been more than 3 inches at any time. There was no doubt that the real cause of rotation was, as indicated by previous speakers, want of parallelism between the hydraulic cylinders and the cylinder of the shield. Special care had been taken by Mr. Rowell and by the makers to secure, in the case of the Baker Street and Waterloo shields, more accurate parallelism than was usual, and with great success. The question raised as to the setting out of the tunnels was rather a side issue to the considerations of tunnelling under the river; but he might describe briefly the general plan adopted and the degree of accuracy obtainable. He had first determined a meridian on the south side of the River Thames by morning and afternoon observations with the theodolite on the opposite limbs of the sun, making the requisite corrections for the change of declination, by adding or deducting from the angle observed the product of half the change of declination, the secant of the latitude and the cosecant of half the observed angle; and then similarly a meridian in Regent's Park near to the other extremity of the line. Those two meridians had been connected with the lines of the street traverse in bearing, so that the traverse carried from one end to the other could be checked with the common direction obtained by the two observations. All the route had been surveyed through the streets at night and the lines had been reduced to true bearing from the north, and each angle point had been reduced to co-ordinates in northings, southings, eastings and westings. The angles had been measured in the streets with 7-inch Troughton-Simms theodolites having micrometer eye-pieces, and he had read every angle on both limbs and repeated the angle without re-setting to zero, thus eliminating one cause of variation, and securing a result which could be relied upon as accurate to within 5 seconds in each angle. The whole of that work, together with the chaining, had been checked

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Mr. Haigh.

independently by the contractors' engineers, who had gone over the same points, and the results had been compared afterwards. The chaining had been done with a ¾-inch steel band 100 feet long, with brass chain handles, which had been carefully compared with the standard on the granite at Trafalgar Square; and by a considerable number of observations the temperature at which the true length was obtained had been ascertained for each band, and the coefficient of expansion determined. The result was that for each degree Fahrenheit of change of temperature the band elongated or contracted 0·0007 foot per 100 feet. The survey through the streets was an open traverse, not a triangulation, and had been taken along the streets under which the railway was to run. From that traverse accurate steel-tape measurements had been taken to kerbstone-edges, building-frontages, and other adjacent details. These having been laid down on the plan, the tunnel-lines had been connected with them by taking the deviations of the centre lines from the traverse-lines, and reducing them to similar bearings from the true north, and fixing the angle points by their relation to the detail determined by the survey, and its connection with the traverse. In measuring, the chain had been laid along the surface, and the reduction to the horizontal effected by levelling along the same course at the chain ends and some intermediate points, and correcting by deducting the square of the rise divided by twice the length from the length measured and calculated from the temperature of the chain. The surface-chaining so done had been reliable to 1 in 20,000, and the results in the tunnels had shown the chainages there on a similar system to be reliable to 1 in 15,000. Comparisons at four junctions of the lines, independently carried from the surface down shafts, had shown no variation as wide as the sum of those limits, while from the river to Piccadilly both tunnel sets showed agreement to 1 in 80,000, and the lines diverged laterally only ¼ inch. No special accuracy was claimed for the results, because differences in observation either accumulated or counterbalanced each other, and there were practical limits which were not as near as that amount, and could not be relied upon to any closer approximation. As an instance of the accuracy with which tunnel lines had been carried, in working southward from Baker Street, Mr. Wentworth-Sheilds, who had had charge during construction between there and Piccadilly, having traversed devious passages from the shaft to the tunnels, and having driven one tunnel about ½ mile into the park, had tested the lines with a bore-hole from the surface, and the correspondence had been such that

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Mr Haigh. although the grouting-hole in the key of the tunnel had not actually received the boring-tool, the bore-hole being 12 inches in diameter, a circle corresponding to that grout-hole could have been laid out on the surface, so that a vertical line would pass through the two circles. As to the levelling, results had shown nowhere a difference of more than a $\frac{1}{4}$ inch between the outside work and the tunnel-junctions, a single Ordnance reference only being worked from. Mr. Fitzmaurice had referred with much emphasis to the striking similarity between the works in construction, appliances and various other matters. The strong contrasts, however, appeared to show that the *ne plus ultra* in that class of tunnelling had not been reached. Attention had already been called to the fact that the Greenwich shield was 14 feet 1 inch in length, while the Baker Street and Waterloo Railway shield was only 9 feet 8½ inches. Mr. Copperthwaite had asked if there had been difficulty in driving the latter shield round a curve. There had been none whatever in driving round the 15-chain curve. After passing through the gravel the trap applicances had been taken off and the shield had been driven nearly to Waterloo, and there would have been no difficulty in driving it round a much sharper curve. The difference in the weight of the iron lining had been alluded to, and the question remained, why should the iron lining of the Greenwich tunnel weigh 4 tons 2 cwt. per lineal yard when in the Baker Street and Waterloo tunnels the lining weighed only 3 tons 10 cwt.? Not only were the flanges at Greenwich so deep that 3 inches less in internal diameter was obtained than in the Baker Street and Waterloo Railway tunnels, but the diameter was further decreased 9 inches by a thick lining of concrete. Moreover, at Greenwich the bolts were exceptionally heavy. The rings were 20 inches long against 18 inches, and the joints were broken at Greenwich and continuous in the other case. As to material, the close sand traversed by most of the Greenwich tunnel was in no way to be compared with the open ballast of the portion of the tunnels at Charing Cross to which his Paper referred. The only parts at all similar were the two ends, at neither of which had a full face of ballast been encountered for any considerable time. According to the progress through those parts the cost at Greenwich must have been considerably in excess of the expenditure in the Charing Cross tunnels; whereas in the 700 feet forming the deepest part of the Greenwich tunnel it must have been considerably less, and not the same to a penny, as Mr. Fitzmaurice had suggested. With regard to Mr. Fitzmaurice's question as to the support of the

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clay jacket at the back of the shield, the 5 lbs. per square inch excess of pressure at the top between the air inside and the hydraulic head outside was sufficient to maintain the space left by the shield below the pugged clay, into which the grout was put. With the diameter of 12 feet the additional pressure of the gravel would not be so much as with a larger diameter. The timbered face did not break up or move at all while the shield was being driven, and remained quite intact until it was removed for setting forward. It was unquestionably proved that for a shield of that size a timbered face was thoroughly satisfactory; but to use timber shutters in the bottom would involve a composite system of working which he would certainly not regard as conducive to speed. He could not see the impossibility of inserting the clay ring for the cutting edge beneath only 5 feet of ballast to the river-bed, as at Blackwall. He was strongly of opinion that it was correct engineering to drive the shield with the face held inert, and not to cause, by the pressure of the rams, that commotion which was inevitable in driving backwards so large a quantity of material, disproportionate to the area of the opening of the shutters, in the way that had been done at Blackwall. Certainly the clay blanket should be retained if there was interposed only 5 feet of ballast to the river-bed; but dragging it in fragments through the shield over the heads of the miners should be avoided. Both at the cutting edge and at all projecting tables and girders, pockets should be prepared for the edge to advance into. If the escape of air would not permit of an opening sufficient to make a hand-hole in the ordinary way, some device might be adopted to afford protection against the escape of air during the progress of the excavation. As to the comparative power required to drive the two shields, as he understood it, the figure of 750 tons quoted in Mr. Copperthwaite's Paper did not represent the actual power in driving, but the capacity of all the rams together. For comparison with that it was necessary to take, in the Baker Street and Waterloo tunnels, fourteen rams, 6 inches in diameter, at 1½ ton per square inch, giving 590 tons. In the ballast and into the clay pocket the shield had usually started with about 80 tons pressure, and the finishing pressure had risen to about 160 tons. By using an air-pressure varying with the tide and equal to the hydrostatic pressure at the invert, excessive pumping had been avoided, the miners had not had to work in water, and the safety of the face had been secured against an inflowing current, which would wash away the pug used to prevent the escape of air. At the

Mr. Haigh.

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Mr. Haigh. Mersey tunnel, if a clay jacket for the shield and a well-pugged face had been adopted, a pressure equal to the hydrostatic pressure could probably have been maintained. The ratios of cavities in the ballast quoted in the Paper were not intended to represent the openness of the coarsest stuff encountered, as they had not been determined from a sufficient number of samples. They might possibly represent an average, but were no guide to the coarsest or most open ballast. Even a sample from the coarsest ballast could not be relied on to represent the whole stuff between it and the river-bed. The air escaped through the most open stuff, and sometimes traversed a considerable horizontal distance in its course to the surface. It was quite possible that the 38 per cent. of cavities mentioned by Mr. Wentworth-Sheilds might have represented some of the material, although the samples referred to in the Paper had shown 25 per cent. to 33 per cent. Sir Alexander Binnie's remarks on the Thames valley were exceedingly interesting; but the connecting links between various observed places were too scanty to afford a decided determination of some of the features he had mentioned. An extensive valley of subsidence might be created under a paltry stream, and the width and depth of the ancient valley might, after the lapse of ages of subsidence, give quite a false impression of the magnitude of its old stream. In extensive lakes and marshes many deep pools existed which had been possibly below the bottom of any pre-existing stream.

Correspondence.

Mr. Manton. Mr. A. WOODROFFE MANTON remarked that he would be glad to have a few further details as to the various items and dimensions of plant used at Poplar; such as boilers, compressors, generators, etc.; the shield-ram pressures under varying conditions, in gravel and in clay, under pressure and before pressure was put on, at the Greenwich tunnel; and the diameter of the soft lead wire behind the caulking, and the size of the space into which it was pressed. As apparently only six to ten rams were used out of fourteen in the Baker Street and Waterloo shield, with the very moderate ram-pressure of 1,300 lbs. per square inch, it would appear to be more economical to use the standard 7-inch ram-cylinders, and the London Hydraulic Power Company's pressure of 800 lbs. per square inch, without the intervention of the 4⅝ to 1 intensifier. He noticed that the rams were constructed in cast steel in place of cast iron. In many shields the use of steel had been attended

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with troublesome leakage through want of compactness in the metal as compared with cast iron, and gun-metal liners had had to be fitted. He would like to know if any such trouble had been experienced. He would also be glad to know whether the marine boilers in the plant of the Baker Street and Waterloo Railway had proved satisfactory as far as coal-consumption and maintenance were concerned. On the work in which he was engaged he had had an opportunity of comparing the consumption of boilers of the marine type with twelve 30 N.HP. to 80 N.HP. boilers of the locomotive type, and he found that the former consumed considerably more than the latter. Further points on which he would like additional information were the pattern of inlet and non-return valve used in the Markham compressors; the reason why separate generators were employed for traction and power purposes, the voltage being the same; and whether, Thames water being apparently available for condensing purposes, the engines used were condensing engines. Mr. Haigh's Paper, relating as it did to subaqueous railway work only, did not deal with the station and cross-over tunnel shields employed; but it would be interesting to know if they were practically identical with those used on the Central London Railway and later works, and if not what the material differences were. Mr. Manton.

Mr. EDMUND WRAGGE remarked that he thought the depression in the clay in the bed of the Thames, referred to by Mr. Haigh, was probably caused by the removal of the foundations which he, as Resident Engineer of the Waterloo and Whitehall Pneumatic Railway, had put in about 35 years ago. He thought he was correct in saying that the cylinder, 21 feet in diameter, which had been sunk some 70 feet below high water to form the pier nearest the Surrey side of the subaqueous tube, had been as nearly as possible in the place where the dip was shown in Mr. Haigh's section of the river. The Waterloo and Whitehall Railway, as some members would recollect, had been intended to be a tube sunk below the bed of the river, and crossing from the then Scotland Yard to College Street, for a pneumatic railway, of which the late Sir Charles Fox and the late Mr. Rammell had been the joint engineers. The tube had been 10 feet in internal diameter, and had been made in four lengths of 235 feet each, the end of each length being supported upon a pier formed of a cylinder 21 feet in diameter and sunk in the bed of the river, which was to be dredged sufficiently deep between piers to permit the tube to lie in a channel between them and to have its top well below the bed. At the time of the commercial collapse of 1866, to which Mr. Wragge.

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Mr. Wragge the discontinuance of the work was due, the two piers nearest the Surrey shore had been sunk, and the bed of the river between them had been dredged ready for placing the tube in position, but although the first tube had been completed, it had never been laid. A portion of the railway under the foundation of the wall of the Thames Embankment, and a short length of tunnel in College Street were, he thought, still where they were constructed, but he believed the cylinders sunk as piers had been removed after he left England for Canada, and the places they had occupied had either been filled or had silted up.

Mr. Haigh. Mr. HAIGH, in reply to the Correspondence, remarked that the steel ram-castings of the Baker Street and Waterloo Railway shield had not given any trouble from want of solidity of the metal; but much care had been necessary on the part of the makers to send out only sound castings. On the other hand, they did not seem to be superior to the cast iron of the ordinary shields. The marine boilers used had small tubes of the locomotive type. The coal-consumption was not economical, the engines being single expansion. The exhaust was to a condenser in the river. The shields for large tunnels—21 feet 2½ inches and 23 feet 9 inches in internal diameter—were in general the same as those used on the Central London Railway and elsewhere. But the cutting-edge ring was flush with the cylindrical shield-skin, not proud. The ring holding the rams was, he believed, slightly thicker in the casting. As to the connection between the Waterloo and Whitehall Railway referred to by Mr. Wragge and the depression in the London clay shown on the longitudinal section (Fig. 2, Plate 1), a cylinder sunk 235 feet from the Surrey shore in continuation of the line of College Street, probably nearly the direction of that projected railway, would agree with the direct distance from the shore of that part of the Baker Street and Waterloo Railway where 70 feet was marked from Trinity high water to the surface of the clay. The fact of the cylinder having been sunk 70 feet would seem to show that at that time the depression had existed, and that the object had been to found on the clay; for the 10-foot tube was to have been laid in a dredged channel close to the river-bed. But the depression had been proved to a depth exceeding 100 feet below Trinity high-water mark. Moreover, it was not conceivable that the disturbance in raising a 21-foot cylinder should have anything to do with a depression nearly 700 feet across the top. With regard to electric supply, separate generators and cables had been used for power and light, to avoid the interference with the lamps which would otherwise have been caused by sudden diversions of the current.

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8 April, 1902.

CHARLES HAWKSLEY, President, in the Chair.

It was announced that the Associate Members hereunder mentioned had been transferred to the class of

Members.

JOHN HENRY BARKER.
GEORGE JOSEPH BELL.
GEORGE FRANK BURN.
JOHN FERGUSON.
FRANCIS DOUGLAS FOX, M.A. (*Cantab.*)
ASTLEY PASTON FRIEND.
WILLIAM KINGSTON, B.E. (*Queen's.*)
CHARLES MAYNE.
GEORGE TAYLOR NICHOLSON
JOHN HALL RIDER.
EDWARD GEORGE RIVERS.

And that the following Candidates had been admitted as

Students.

MOHOMED AHSAN.
JOHN CHARLES BARRACK.
ROLAND HIRST BEAUMONT.
DOUGLAS RAYMOND BENNETT.
PERCIVAL GORDON BENNETT-POWELL.
CHARLES ROXBERRY BLAND.
THOMAS LACEY BONSTOW.
FREDERICK THOMAS BOWLER.
ALFRED HENRY BRISTOW.
DANSIE WILLIAM CARTER.
HUGH BOWDEN CURRIE.
JOHN DARELAN DAVIS.
FRANK GEORGE FINCH.
MAURICE NORMAN FORSTER.
EDWARD TYRRELL DUNKIN FRANCIS.
ROBERT FYNES-CLINTON.
JOHN GARDNER.
DOUGLAS HEUGH GIBSON.
THOMAS OLIVER GOODING.
REGINALD VICTOR GREGORY.
BLACKWOOD HALLOWES.
FREDERICK BERKELEY BRUCE HARMAN.
HUGH PERCY HEAP.
WILLIAM HEPWORTH.
HUBERT MERVYN TYLSTON HODGSON.
REGINALD HODGSON.
CHARLES WILLIAM HOGG,
ARTHUR HENRY IMBER.
WILLIAM COLLINSON ISLE.
ALBAN CAMPBELL MACKENZIE.
WILLIAM JOHN MARLOW.
ERNEST FORD WATSON MAYHEW.
JOHN ROBERT MEAD.
FREDERICK CHARLES MEYRICK
ROBERT CECIL MILLIKEN.
SYDNEY HUBERT MORGAN.
RICHARD VIVIAN MORRIS.
WALTER MURRAY.
OSCAR TRAVERS NETTLETON.
EDWARD SIDNEY PINK.
ARTHUR POPE.
FREDERICK WALTER PURSE.
SIDNEY ROBERT RAFFETY.
BERNARD ROYCE.
CHRISTOPHER CLARKE ROYSTON.
FRANK SCHOFIELD.
HUGH SCOTT.
EVELYN SPENCER.
ARTHUR DOUGLAS SPOONER.
GEORGE NORMAN VERE THOMPSON.
PERCIVAL MERVYN TREMLETT.
ARTHUR MOORE WALTON.
HARRY WORTHINGTON POPE.

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The Candidates balloted for and duly elected were: as

Associate Members.

JOSHUA EDWARD ACFIELD.
ARTHUR HENRY ALCOCK.
ARTHUR MARSHALL ARTER, Stud. Inst. C.E.
WILLIAM LOWE ATKINSON.
WILLIAM AUBREY AYLMER BATTLE.
GERALD RICKETT BLACKBURN.
CHARLES ROBERT DUDLEY BORRETT.
HUGH BRODHURST, M.A. (*Cantab.*)
WALTER ERNEST BUSH.
WILLIAM CARNEGIE.
JOHN DEWAR CORMACK, B.Sc. (*Glas.*)
GEORGE HENRY CORRINGHAM.
ERNEST MCLEOD DOWSON, Stud. Inst. C.E.
FREDERICK AINSLIE DROUGHT, B.E. (*Royal.*)
JOHN WILLIAM SLOAN EMERSON.
ALECK ROBERT GIBBS.
WILLIAM JAMES GOW.
JAMES RENNIE GREIG.
JOHN WILLIAM GRIFFITH, M.A., B.A.I. (*Dubl.*)
WILLIAM JAMES GUYATT.
WILLIAM HENRY HAIGH.
HENRY THOMAS HILDAGE.
RALPH FREDERICK HINDMARSH.
BENJAMIN HOWDLE.
BARNARD HUMPHREY.
WILLIAM HUTCHISON.
JOHN IRVINE.
GEORGE JERRAM.
HERBERT LAPWORTH, B.Sc. (*Birm.*)
CYRIL EDWARD LLOYD.
JAMES THOMSON MAXWELL, B.Sc. (*Edin.*)
ALEXANDER MILLAR.
WILLIAM MORGAN MOYLAN.
CHARLES FRANKLIN MURPHY.
JAMES JUST NIVEN.
JOHN SWITZER OWENS.
FREDERICK CHARLES RICHARD PALMER.
GEOFFREY PORTER.
WILLIAM WALTON PREECE.
JOHN DOWNIE PROPHET.
ALBERT CHORLEY ROGERSON.
CHARLES EMILE HERBERT SALMON.
WILLIAM CROASDILL SHETTLE.
ROBERT CHERRY SIKES, B.E., B.A. (*Royal.*)
HUGH LESLIE SMITH.
FRANK COSTON TAYLOR, B.A. (*Cantab.* Stud. Inst. C.E.
WILLIAM ARTHUR THAIN.
GODFREY WARD.
WILLIAM WATTS.
JOHN BURDETT WILLIS, Stud. Inst. C.E.
JOHN FAIRWEATHER WILSON.
FRANK WRIGHT.

The discussion upon the Papers by Messrs. Copperthwaite and Haigh, on "The Greenwich Footway Tunnel" and "Subaqueous Tunnelling through the Thames Gravel: Baker Street and Waterloo Railway," occupied the evening.

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15 April, 1902.

CHARLES HAWKSLEY, President,
in the Chair.

The discussion upon the Papers by Messrs. Copperthwaite and Haigh on Tunnelling under the River Thames was continued and concluded.

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22 April, 1902.

CHARLES HAWKSLEY, President,
in the Chair.

It was resolved—That Messrs. J. V. W. Amor, G. E. W. Cruttwell, F. Hudleston, E. L. Mansergh, A. H. Preece, R. J. G. Read, J. J. Webster and L. S. Zachariasen be appointed to act as Scrutineers, in accordance with the By-laws, of the Ballot for the election of the Council for the year 1902–1903.

It was announced that the Associate Members hereunder mentioned had been transferred to the class of

Members.

HARRY HERBERT LAKE.
PERCY ARCHIBALD LOW.
WILLIAM LUNN.
HARRY POWELL MILES.
ARTHUR MUSKER.
CHARLES HENRY PRIESTLEY.
HERBERT FREDERICK TOMALIN.
JOHN HENRY WHIELDON.

And that the following Candidates had been admitted as

Students.

JOHN JOSEPH MURPHY.
ALAN OCTAVIUS WHITEHEAD.

The Candidates balloted for and duly elected were: as

A Member.

GEORGE DEUCHARS.

Associate Members.

VERNON COOPER, Stud. Inst. C.E.
JAMES CHARLES HERBERT CROSLAND, Stud. Inst. C.E.
RICHARD LAWSON LAFFÈRE, B.A.I. (*Dubl.*)
EDWARD NATHANIEL PEARCE.
CHARLES EDWARD SHACKLE.

(Paper No. 3346.)

"Locomotive Fire-box Stays."

By FRANCIS WILLIAM WEBB, Vice-President Inst. C.E.

In view of the large amount of attention which locomotive engineers at home and abroad have given in recent years to the question of the most suitable material for the staying of locomotive fire-

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boxes, chiefly owing to increased boiler-pressures, the Author's experience in this direction, together with the results of an investigation made by him on the subject, may be of interest, especially to those concerned in the construction of locomotives.

At the present time the London and North Western Railway Company have 3,000 locomotives, with boiler-pressures varying between 120 lbs. and 200 lbs. per square inch. With ten exceptions of a special design, all the boilers are fitted with copper fire-box stays, varying in diameter between $\frac{7}{8}$ inch and $1\frac{1}{8}$ inch. In accordance with the experience of most locomotive engineers, it has been found necessary to renew a number of stays from time to time, owing either to wastage of the heads, to leakage or to breakage. Wastage occurs principally in the vicinity of the brick arch: breakages occur chiefly at the right and left-hand front top corners, in a direction more or less diagonal across the plates. Sometimes the stays break in a similar diagonal direction, but commencing at the back top corners of the side plates. As is well known, these breakages are chiefly due to the expansion and contraction of the inner copper casing of the box. Photographs of two typical fractures of stays are given in Figs. 1, Plate 4. Breakage of the stays in the lower part of the box—which is not frequent—is invariably due to the stays being thickly coated with boiler-scale, and consequently becoming over-heated.

From time to time various alloys have been offered as substitutes for copper, owing to their possessing a greater tensile strength. In the hope of obtaining a material superior to copper, some of these have been tried practically; and this Paper records the results of such trials and of the Author's recent experience with copper stays.

Copper.

Under this head is given the Author's experience as far as it relates to the use of copper stays in the boilers of the latest fifty four-cylinder compound express passenger engines on the London and North Western Railway, all of which work at a steam-pressure of 200 lbs. per square inch. The foremen have strict instructions that all leaky stays, or stays with wasted heads, are to be replaced at once; and, further, that the boilers are to be often and well washed out.

In June, 1897, the first of the forty four-cylinder compound express passenger engines of the "Diamond Jubilee" class commenced to run, having a boiler-pressure of 200 lbs. per square inch, and the fire-boxes stayed with $1\frac{1}{8}$-inch copper stays; and up to

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the 31st December, 1901, the aggregate mileage for these engines was 5,622,064 miles. The total number of copper stays replaced during that period was 6,663, or one stay per 844 miles. None of the stays replaced are recorded as broken, although no doubt some few were, but not sufficiently so to require a special entry. Wasted heads and leakage are given as the reasons for replacement.

One stay per 844 miles may appear at first sight to be rather a large percentage; but, as each boiler contains 996 copper stays, the engine would have to run a distance of 840,500 miles before all the stays (or a number equal to all) would be replaced; which, it must be admitted, compares favourably with the renewal of other parts of the engine for such a distance. Further, these engines are worked very hard, the average speed being 50 miles per hour, hauling a load of 350 tons to 400 tons, including engine and tender; and many of them run 158 miles in 3 hours and 10 minutes without a stop, consuming coal at the rate of 1 ton per hour.

In June, 1901, the first of the ten four-cylinder compound express passenger engines of the "Alfred the Great" class commenced to run, having a boiler-pressure of 200 lbs. per square inch, and the fire-box stayed with 1,032 copper stays $1\frac{1}{16}$ inch in diameter; and up to the 31st December last the aggregate mileage covered by these engines was 277,800 miles (greatest mileage, 43,000; least, 17,000); but no copper stays had to be replaced during that period.

Without discussing here the merits or demerits of copper for the stays of these high-pressure boilers, it has, in the Author's opinion, answered satisfactorily.

Copper-Zinc Alloy (40 per cent. of Zinc).

In 1897 the fire-box of a passenger engine (boiler-pressure 150 lbs. per square inch) was stayed with 1-inch stays of a special copper-zinc alloy manufactured for the purpose. Each stay was riveted in accordance with the usual practice with copper. The engine commenced to run in April, 1898. After running 82,020 miles (up to September, 1899), twelve stays were replaced by copper, owing to leakage, and one hundred and thirty-three others were drilled and drifted; after a further mileage of 72,713 miles, fifteen more were replaced by copper, and all the remainder were fullered in December, 1900. In January, 1901, all the stays were re-riveted; and in April, 1901, owing to their leaking so badly as to render the boiler unsafe for working, it was decided to replace all the copper-zinc stays with copper stays, the total mileage

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for the boiler being 169,058 miles. As the fire-box contained 646 stays, the life of this copper-zinc alloy is equal to only 262 miles per stay, at a boiler-pressure of only 150 lbs. per square inch.

The material not having given the satisfaction claimed for it, a number of the stays were removed from each side of the box, care being taken not to damage the threads in the copper plate; in fact, after being drilled from the shell-plate, they came away from the copper plate with a very slight blow, indicating that they were held in position only by the scale surrounding them. On examination of their heads and threads it was observed that they were much wasted. The surface of the threads was still coated with scale, proving that they had not been damaged in removal.

Three stays from each plate, selected at random, were cut in two longitudinally, and one half of each was polished and etched. Fig. 2, Plate 4, is a full-size view of one of them, as removed from the box. It shows the extent to which the wastage has taken place, and is representative of the twelve. The significant feature, however, is that cracks are seen in them all, running from the bases of a number of threads towards the head, at an angle of about 45°. Figs. 3 and 4 show the longest and the shortest cracks, magnified four diameters. It will be observed also that the threads are badly wasted, which accounts for the excessive leakage of the boiler.

With a view to ascertain the uniformity or otherwise of the chemical composition of the stays, separate samples marked C, E, and H (Fig. 2) were taken from the centre and the edge of the body of the stay, and from the surface of the head, the analyses of which are as follows:—

ANALYSES OF COPPER-ZINC ALLOY.

Element.	Sample from Centre.	Sample from Edge.	Mean of Centre and Edge.	Sample from surface of Head.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Copper	60·21	60·25	60·23	61·05
Zinc	39·55	39·66	39·61	38·84
Iron	0·32	0·25	0·28	0·23
Manganese	0·04	0·02	0·03	0·04
Arsenic	0·096	0·096	0·096	0·096
Antimony	0·012	0·012	0·012	0·012
Lead	Trace	Trace	Trace	Trace
Phosphorus	Trace	Trace	Trace	Trace
	100·228	100·288	100·258	100·268

Ratio of copper to zinc, *1·52 : 1* (analysis).

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From these results it is evident that the stays have not lost zinc by contact with the water of the boiler; there is, however, a slight loss of zinc from the surface of the head.

The holes in the heads of the stays were partly filled with a black deposit; some of this was scraped out, care being taken not to touch the metal of the stay, and the copper and zinc in it were estimated, showing copper 5·75 per cent., zinc 2·68 per cent., and ratio of copper to zinc 2·14 : 1. The deposit was then removed entirely from some of the holes, revealing a surface distinctly coppery in appearance. This points to slight wastage at the heads of the stays, due to loss of zinc by volatilization owing to the high temperature of the box, but not sufficient, in the Author's opinion, to warrant the statement that the alloy has suffered loss of zinc.

Copper-Zinc Alloy (9 per cent. of Zinc).

In September, 1891, the fire-box of a six-wheel-coupled coal-engine (boiler-pressure 150 lbs. per square inch) was fitted with 1-inch stays of this alloy, riveted in the usual way. Between that date and the 31st December, 1901, fifty-one stays were replaced by copper; fourteen of them had broken, and the remaining thirty-seven were removed owing to wasted heads and leakage. The total mileage was 284,978 miles, equivalent to one stay replaced per 5,588 miles.

The chemical analysis of the alloy is as follows:—

	Per Cent.
Copper	89·75
Zinc	9·09
Tin	0·76
Lead	0·08
Phosphorus	0·03
Iron, Manganese, Arsenic, Carbon	Traces.
	99·71

The tensile test at the ordinary temperature gave a breaking-weight of 20 tons per square inch; elongation 55 per cent. on a length of 2 inches; contraction of area 64 per cent. The average of seven similar engines stayed with 1-inch copper stays, working the same kind of traffic between 1891 and December, 1901, gives one stay renewed per 1,805 miles. Thus the results of the 9-per cent. zinc alloy compared with copper are highly satisfactory. Unfortunately none of the material remained after staying the boiler, so

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that the alloy could not be included in the investigation referred to later.

Copper-Tin Alloy (3 per cent. of Tin).

In 1897 the fire-box of an express goods engine (six wheels coupled; boiler-pressure 150 lbs. per square inch) was fitted with 1-inch stays of a special copper-tin alloy, the usual practice of riveting being adhered to. The engine commenced to run in July, 1897. After running 93,290 miles (up to March, 1901) one hundred and forty-five stays were removed, owing to their being loose in the holes and having wasted heads; but none of them were broken. Up to the 31st December, 1901, the engine has not required further repairs, the total mileage being 113,657 miles, or one stay renewed per 791 miles. Four other boilers have been stayed with the same alloy, but have not been running long enough to afford any basis for comparison.

Copper-Aluminium Alloy.

The merits of copper-aluminium alloys have often been proclaimed; and results of mechanical tests at ordinary and at steam temperatures having been given to show their suitability for positions in which the metal is subject to heat and stress combined, the Author decided in August, 1900, to make a trial of a 7½-per cent. aluminium alloy for fire-box stays. The figures submitted with a sample rod, and the results of the tests thereof by the London and North Western Railway, are as follows:—

	Temperature of Test. Fahr.	Breaking Weight per Square Inch.	Elongation, on Length of 2 Inches.	Contraction of Area.	Remark.
	Degrees.	Tons.	Per Cent.	Per Cent.	
Maker's tests . .	60	27·5	80·0	..	
	374	24·7	80·0	..	
London and North Western Railway test	60	25·9	89·0	70·1	Good sound fracture.
Cold bending test .	Bent close upon itself without signs of cracking.				

The fire-box of an express goods engine (six wheels coupled, boiler-pressure 150 lbs. per square inch) was stayed with 1-inch stays of this alloy, riveted in the Company's usual way. The engine commenced to run in January, 1901, but had to be taken

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off the line after being in use only 2 months and running 2,400 miles, owing to a number of stays being broken—some in the copper plate, some in the steel plate: a number of others had the heads broken clean away, thus causing the copper plates to bulge.

The fractured ends of the stays were not uniform in appearance, some having broken off very irregularly with large crystalline faces, while others were more regular in fracture and presented smaller crystals. Several of them were sectioned longitudinally, polished and etched. Fig. 5, Plate 4, is a full-size view of a stay which broke at both ends. Figs. 6, 7, and 8 show the structure of stays which are typical of all those examined. Fig. 9 is a photo graph showing the fracture of a broken head. A large crystalline structure does not explain the breakages; for out of eighteen stays, the ends of which were examined, twelve showed the more regular fracture, and consequently the comparatively small crystalline structure, exemplified by Fig. 6.

Chemical analysis of the stays showed that commercially pure copper and aluminium had been employed in the manufacture of the alloy, and no injurious elements were present to account for their failure:—

	Per Cent.
Copper	93·18
Aluminium	6·88
Phosphorus	Mere trace
	100·06

The average tensile strength of four broken stays at the ordinary temperature was 25·3 tons per square inch.

Mild Steel (Bessemer).

Steel stays have been well tried, both solid for riveting and drilled for drifting; but, owing to the well-known difficulty of keeping a steam-tight joint in the copper plate, their use in copper fire-boxes has been abandoned. Particulars of a passenger engine (boiler-pressure 150 lbs. per square inch), fitted with steel stays, may, however, be of interest. The engine was put in use in January, 1889; in January, 1892, two hundred and eighty-seven stays were replaced by copper ones. In July, 1897, a further two hundred and thirty-nine were replaced by copper, and in June, 1899, thirty-two more were so replaced. In 1901 the boiler was scrapped. Total mileage 340,839.

An alloy of copper and manganese, containing 4 per cent. of

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manganese, has been offered to the Author, but up to the present time it has not been given a trial. However, from a report[1] of a practical trial of such an alloy for high-pressure locomotives, made by Mr. du Bousquet, of the Northern Railway of France, it appears to answer satisfactorily.

From this account of trials in practice of the above-mentioned substitutes for copper, it will be admitted that none of them, all things considered, show any improvement on copper, except perhaps the copper-zinc (9 per cent. zinc) alloy. The chief recommendation of each of them has been its greater strength compared with copper; but evidently increased strength is not all that is required, seeing that the broken copper-aluminium stays gave 25·3 tons per square inch, with an elongation superior to copper: yet no one would knowingly use an alloy with such a distinctly crystalline structure as that indicated by Figs. 7 and 8, Plate 4.

Owing to the failure of the copper-zinc alloy (40 per cent. zinc) and the complete failure of the copper-aluminium alloy, the Author arranged to have the matter investigated more closely.

Investigation as to the Comparative Suitability of Copper and Copper Alloys for Fire-box Stays.

The physical condition of alloys generally at various temperatures has recently received the careful attention of many scientific men, particularly in this country of Sir William Roberts-Austen, K.C.B., Hon. M. Inst. C.E., who has determined the tenacity of various alloys at temperatures up to 900° F., showing in some instances a loss of 85 per cent. in strength.[2]

From published results it would appear to be the usual practice of engineers to test fire-box stays at a temperature corresponding with the steam-pressure at which they are intended to be worked. It has been pointed out,[3] however, by Mr. Le Chatelier that the copper plates of locomotive fire-boxes may attain a temperature of 750° F.; and Mr. T. Hurry Riches, M. Inst. C.E., considers[4] that a temperature of 800° F. may exist at the surface of the stay-heads, and that a mean temperature of 600° F. is not improbable at a distance of ½ inch from the heads.

In order to ascertain the temperature which fire-box stays may attain, the Author fitted a stationary boiler of the standard loco-

[1] *Revue générale des Chemins de Fer*, March 1901, p. 248. See also *post*, p. 126.
[2] Reports to the Alloys Research Committee, Inst. Mechanical Engineers.
[3] *Le Génie Civil*, vol. xix. p. 60. [4] *The Mechanical Engineer*, 1901, p. 200.

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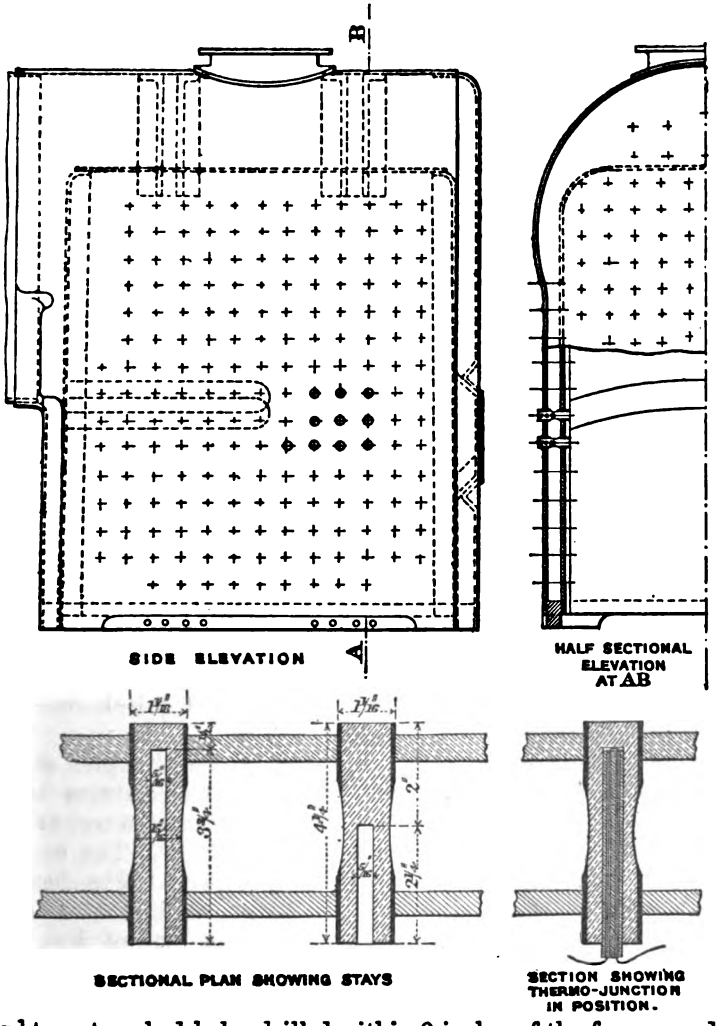
motive type (boiler-pressure 120 lbs. per square inch) with seven stays made of the materials Nos. 1–5 (Appendix). Five of them had holes drilled down the centre to within ½ inch of the furnace end,

Figs. 10.



and two stays had holes drilled within 2 inches of the furnace end. They were all screwed ¼ inch through the copper plate (*Figs. 10*).

A portable electrical pyrometer, fitted with platinum and platinum-rhodium thermo-couple which could be read accurately

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to 5° C., was employed for determining the temperature. The following Table gives the results recorded:—

Material of Stay.	Temperature.	
	Boiler steaming heavily and blowing off.	Boiler steaming lightly but blowing off.
Stay with hole drilled to within ½ inch of furnace end.		
No. 1. Copper rod	215° C. (419° F.)	185° C. (365° F.)
„ 2. Copper-tin alloy	215° „ (419° „)	190° „ (374° „)
„ 3. Copper-zinc alloy	220° „ (428° „)	185° „ (365° „)
„ 4. Copper-aluminium alloy	230° „ (446° „)	190° „ (374° „)
„ 5. Mild steel (Bessemer) rod	215° „ (419° „)	185° „ (365° „)
Stay with hole drilled to within 2 inches of furnace end.		
No. 1.	170° C. (338° F.)	170° C. (338° F.)
„ 3.	175° „ (347° „)	165° „ (329° „)

The temperature of saturated steam at 120 lbs. per square inch is given as 350° F.

An attempt was also made to determine the temperature of the surface of the copper plate, and of the ends of the stays inside the fire-box, in the vicinity of the brick arch, by well insulating the thermo-couple, except the junction which was pressed against the plate or stay. The average of four tests gave a temperature of 540° C. (1,000° F.) for the surface of the copper plate, and 615° C. (1,140° F.) for the surface of the ends of the stays, which projected ¼ inch from the copper plate. From these figures it is fair to assume that in an express locomotive working at a pressure of 200 lbs. per square inch the temperature of the metal in similar positions would be higher, and that 600° F. at ½ inch from the stay-head would doubtless be reached.

Tensile Tests.—As knowledge of the tensile strengths of the alloys already referred to was limited to temperatures below 400° F., a series of tests was made at the temperatures of 60°, 200°, 300°, 400°, 500°, 600°, 700°, and 750° F. The testing-machine used was a Buckton single-lever machine. The chemical analyses of the several materials tested are given in Tables I.–VI. in the Appendix. Three tests were made of each of Nos. 1–5. No. 6 was a specimen rod submitted, which sufficed for only one test at each temperature. All the test-pieces were 5 inches in length, and 0·564 inch in diameter; and the elongation was measured on a length of 2 inches. A specimen is shown in position in *Figs. 11* and *11a*.

When under preparation, all the test-pieces except the copper-

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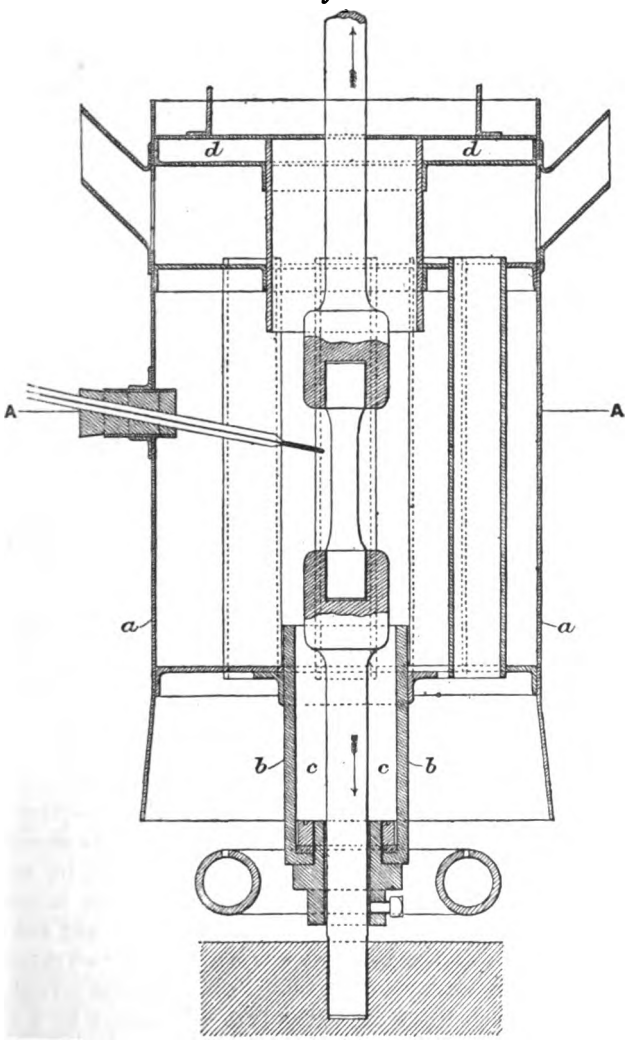
aluminium alloy were found to be highly uniform and homogeneous in structure. Pieces of the copper-aluminium alloy from the same

Fig. 11.



SECTIONAL ELEVATION

Scale 1⅛ inch = 1 Foot.

AIR-BATH FOR TENSILE TESTS AT HIGH TEMPERATURES.

rod varied in structure to the extent shown in Figs. 12, 13, and

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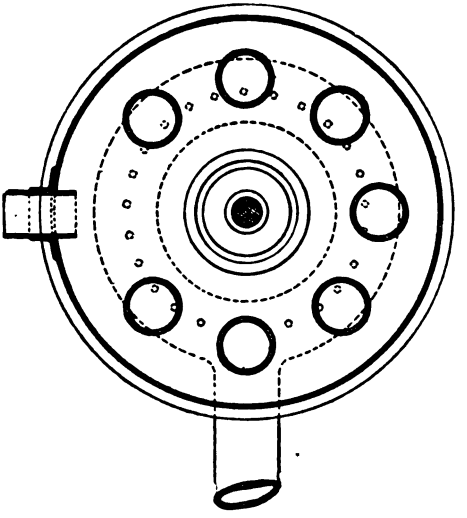
14, which are magnified four diameters. It was also observed that the crystals were either large (Fig. 14) or small (Fig. 12), or large and small mixed (Fig. 13), but not of intermediate size. In view of this heterogeneous structure, the three test-pieces of the copper-aluminium alloy for each temperature consisted of one piece of all large crystals, marked "L"; one piece of all small crystals, marked "S"; and one piece, as nearly like Fig. 13 as possible, marked "M." Separate chemical analyses of large-crystal and small-crystal test-pieces showed them to contain the same percentage of aluminium (7·13 per cent.).

Fig. 11a.



SECTIONAL PLAN ON A.A.

AIR-BATH FOR TENSILE TESTS AT HIGH TEMPERATURES.

Arrangements for Heating Test-pieces. — For the temperatures of 700° and 750° F., an air-bath was used, which is shown in *Figs. 11* and *11a*. It consists of a copper cylinder, in which are fitted seven 1-inch copper tubes; and the whole is carried on the bottom holder of the testing-machine by a nut and set screw. The outside of the bath (*a*) was covered by two sheets of asbestos, as was also the supporting tube (*b*). The spaces (*c*) and (*d*) were packed with asbestos wool. The bath was heated by a ring bunsen burner. For the temperatures 200° F. to 600° F. inclusive, an oil-bath, which has been described[1] by Mr. John A. F. Aspinall,

[1] Second Report to the Alloys Research Committee, Inst. Mechanical Engineers, 1893, p. 102.

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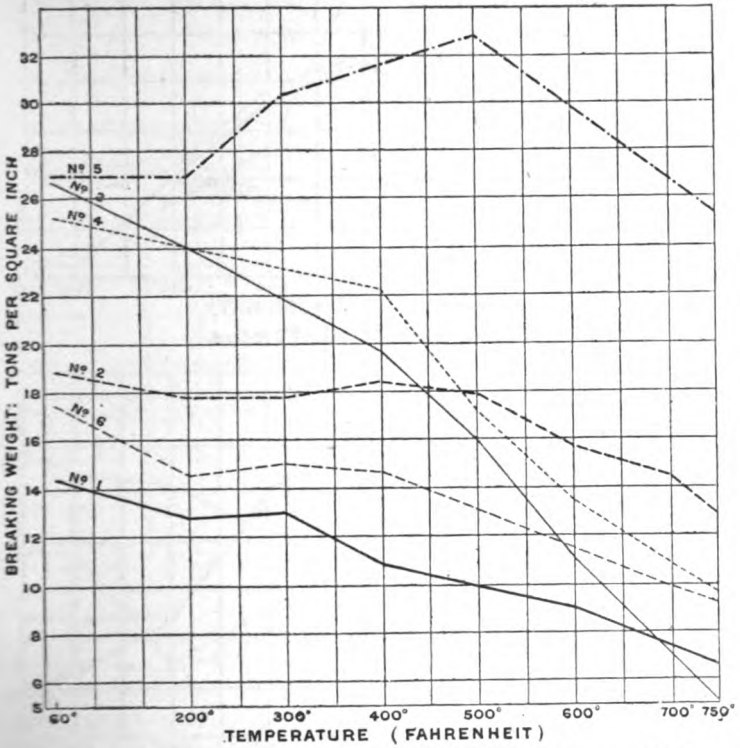
M. Inst. C.E., was used. The temperature was indicated by a mercurial thermometer.

Details of Tests.—Each test-piece was kept at the required temperature for 30 minutes before the first application of load; and the load was then applied at such a rate that fracture occurred in about 15 minutes, the recorded temperature never varying more than 10° F. during the test.

Fig. 15.



TENSILE STRENGTH OF FIRE-BOX STAYS BETWEEN 60° F. AND 750° F.

The results of the tests are given in Tables I.–VII., and the mean results are shown graphically in *Figs. 15* and *15a*. *Fig. 16* shows the variation in strength of the large- and small-crystal test-pieces of copper-aluminium alloy.

General Remarks on the Tensile Tests.—The uniformity of the rods tested—except copper-aluminium, Table IV.—is shown by the closeness of the results at the various temperatures. Through

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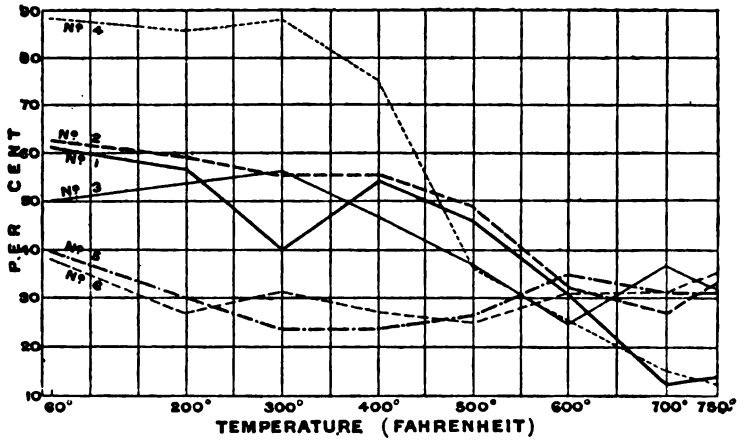
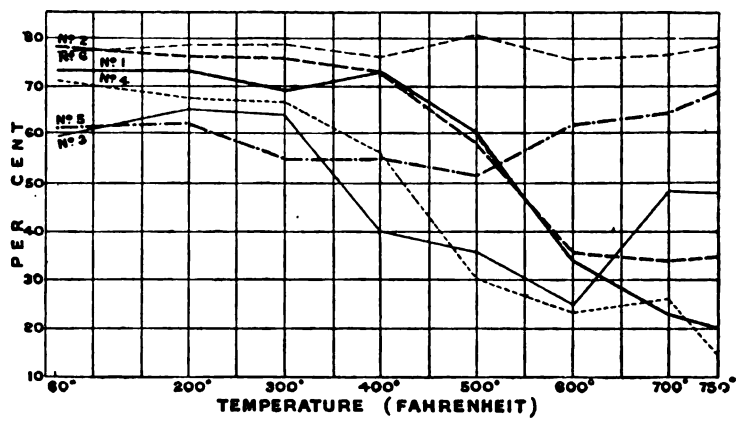
the whole range of tests, the fractures of the steel and of the special rolled copper are characteristic of ductile metals.

The fractures of the copper and of the copper-tin alloy at 600° F.

Figs. 15a.



Elongation on a Length of 2 inches.



Contraction of Area.

DUCTILITY OF FIRE-BOX STAYS BETWEEN 60° F. AND 750° F.

and upwards have distinctly a cast appearance; and copper-zinc and copper-aluminium alloys have a similar appearance at 500° F. and upwards. The special rolled copper rod (No. 6) behaved most satisfactorily, its contraction of area and elongation at all temperatures being very uniform. It is worthy of further consideration.

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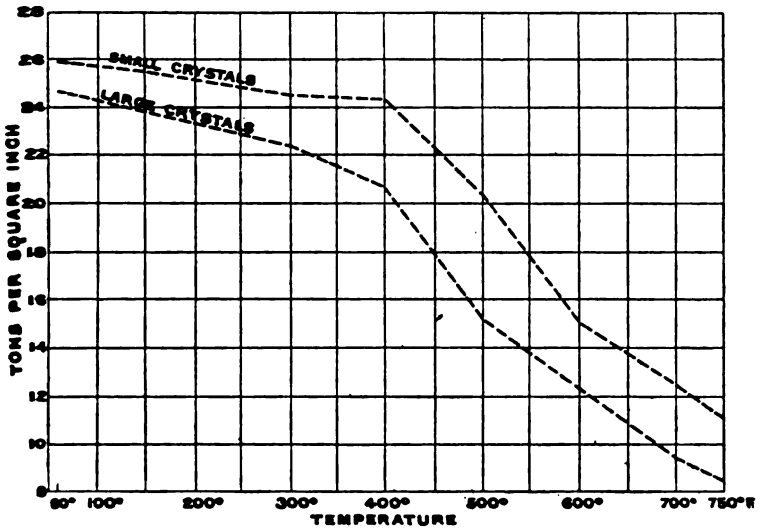
The Copper-Aluminium Alloy.—The great variation in structure of this alloy is strikingly shown throughout the tensile tests. Below 400° F., all tests "L" show distinct crinkling on the extended length; tests "S" show practically none; while tests "M" invariably show distinct crinkling down two opposite sides (Fig. 17, Plate 4), but practically none down the other two (Fig. 18). Fig. 19 is an end view of this stay, and shows that where the crinkling is greatest the crystals are largest.

While the tests at 400° F. and higher temperatures were in

Fig. 16.



VARIATION IN STRENGTH OF ROLLED COPPER-ALUMINIUM ALLOY (7·1 PER CENT. ALUMINIUM) BETWEEN 60° F. AND 750° F.

progress, a sharp grating noise was heard when the test-piece was extending, which increased in distinctness at the higher temperatures. On examining the specimens after fracture, a number of transverse cracks, varying in size, were observed. Photographs of portions of test-pieces "L" and "S" at temperatures of 400° and 500° F. are given in Figs. 20–23, Plate 4. This noise was evidently caused by sudden development of the cracks, due undoubtedly to the want of ductility at high temperatures.

Mr. Charpy and Sir William Roberts-Austen have shown[1] that

[1] Fourth Report to the Alloys Research Committee, Inst. Mechanical Engineers. Proceedings, 1897, p. 39.

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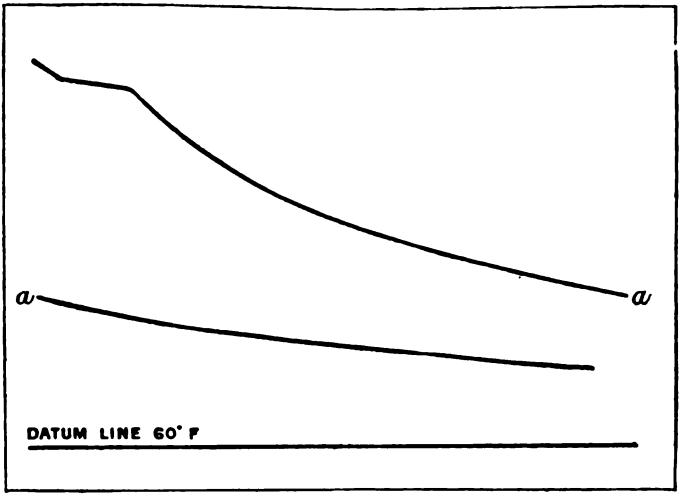
the weakening effect of heat on certain brasses is due to the presence of a portion (a eutectic) melting at a low temperature. This point naturally received consideration. A cooling-curve (*Fig. 24*) was determined, but no second break was revealed, and consequently the curve throws no light on the subject. Further, as the alloy contains no injurious elements, it would appear that its weakness at temperatures above 400° F. is due to want of cohesion between the faces of the crystals of which it is composed. Large crystals will develop if a small-crystal specimen be exposed for a short time to a temperature below red heat (Figs. 25 and 26, Plate 5).

Fig. 24.



Cooling-curve of Copper-Aluminium Rolled Rod from the Solidifying Point (about 1,900° F.) to 482° F.

Riveting Copper and Copper Alloys, etc., in Copper Plates.—On examining the leaky stays of the copper-zinc alloy, which during their life had been drilled and drifted, it was not possible to say whether the cracks at the bases of the threads were caused by the original riveting or by the subsequent drifting. With a view to ascertain the effect due to riveting alone, stays of each kind of metal, Nos. 1, 3, 4 and 5, were prepared in the ordinary way and were riveted into a piece of copper fire-box plate. They were then cut from the plate with the copper surrounding the threads, sectioned longitudinally, polished and etched (Figs. 27–30, Plate 5). It will be observed that the copper stay is the

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only one of the four that has made a really good joint; each of the others distinctly shows imperfect contact between the threads of the stay and the plate. In fact, when the specimens were cut in two, the copper plate fell away from three specimens (Figs. 28–30), but remained fast in the other (Fig. 27). The riveting did not produce any marked change in the structure of the alloys.

These tests show that, except in the copper stay, the effect of riveting has been to expand the hole in the copper plate at the base, and also to damage the plate under the riveted head. Seeing, however, that the above results had not been obtained in actual practice, further specimens of Nos. 1, 2, 3, 4 and 5 were prepared, screwed into position in a fire-box, and riveted up in both plates: all done exactly in accordance with the Author's usual practice. They were cut out, with the copper or steel plate surrounding the threads, and were sectioned longitudinally, polished and etched (Figs. 31–35, Plate 5). The results undoubtedly point in the same direction as the preliminary tests, although the copper stay in Fig. 31 is not nearly as good a fit as that in Fig. 27: it is certainly, however, the best result of this series. Fig. 36 shows a bad joint made by using a stay with defective threads. Fig. 37 shows a joint made by the copper-zinc alloy in the steel plate.

It is evident from these riveting tests that the relative hardness of each stay, compared with the copper plate and the copper box into which it is riveted, is of great importance. With reference to the copper stays and fire-box plate, chemical analysis showed the hardening element to be arsenic, of which the quantity present in each case was as follows:—

Preliminary Tests—

Copper plate . .	0·55 per cent. of arsenic	Joint excellent. (Fig. 27.)
„ stay . .	0·34 „ „ „	

Practical Tests—

Copper plate (from fire-box.) . .	0·21 per cent. of arsenic	Joint not so good as above. (Fig. 31.)
Copper stay . .	0·26 „ „ „	

These figures account for the different riveting results obtained with copper.

In order to compare the relative hardness of the material used in these tests, recourse was had to the indentation test for hardness, devised by Professor W. C. Unwin, F.R.S.[1] Three tests were made with each specimen. The load, P, and the depth of

[1] Minutes of Proceedings Inst. C.E., vol. cxxix. p. 334.

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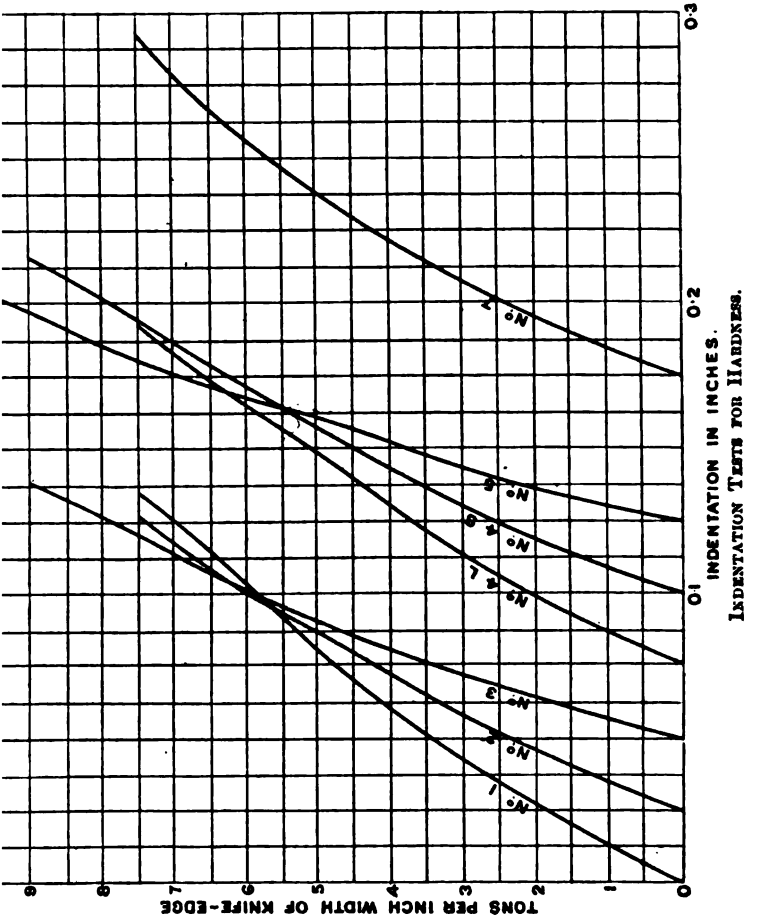
dentation, i, are shown in *Fig 38*; and the hardness-number, C, is lculated according to the formula:—

$$C = \frac{P^{1\cdot2}}{i}.$$



The Table on page 105 gives the mean hardness-number of the hree tests.

Figs. 39 and 40, Plate 5, show the hardness test-pieces of copper-luminium alloy. It will be observed that the effect of the pressure has been to force the crystals out at the side of the test-iece, this being very marked in Fig. 40.

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The "hardness-number," therefore, together with the results of the riveting-tests, shows clearly that the riveting of a hard stay into a comparatively soft copper plate is the cause of the enlargment of the hole, and the consequent formation of an unsatisfactory joint; and this is, in all probability, the cause of the initial leaking of the stays made of the copper-zinc alloy. Further, in these experiments it has been noticed repeatedly that the effect of screwing a hard stay into a copper plate is to cut away part of the copper threads, leaving them thin.

Reference No. on Diagram. (Fig. 38.)	Particulars of Specimen.	Width of Specimen.	Mean Hardness-Number.
		Inch.	
1	Copper, rolled rod	0·483	84·8
2	Copper-tin alloy, rolled rod	0·494	110·0
3	Copper-zinc „ „ „	0·494	166·5
4 L	Copper-aluminium alloy, rolled rod, large crystals	0·494	93·2 [1]
4 S	„ „ „ „ „ small „ .	0·482	120·4 [1]
5	Mild steel (Bessemer) „ „	0·483	197·3
7	Arsenical copper, rolled plate	0·482	109·7

Fig. 41 is a section of a copper stay—selected at random—cut from a fire-box after 7 years' service; and although the head is much wasted, the joint is very good. Fig. 42 is a steel stay from the same fire-box after 12 years' service; the threads are almost corroded away, and their holding power must have been practically nil, the space between the threads being filled with corroded metal and boiler-scale, which were responsible for the joint. Fig. 43 is a copper stay from another boiler, cut from both plates after 8 years' service; although the joint is not as good as that shown in Fig. 41, it is satisfactory.

In conclusion, the Author thinks it will be agreed from this investigation that great tensile strength and ductility combined are not by any means the most important factors to be considered when selecting a material for stays in locomotive copper fire-boxes; but that, whatever the composition of the stay may be, it should be softer than the copper fire-box plate into which it is riveted.

The Paper is accompanied by forty-two diagrams and photographs, from which Plates 4 and 5 and the Figures in the text have been prepared.

[1] In the riveting-tests small-crystal stays were used.

[ADDENDUM.

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ADDENDUM.

NOTE ON THE WASTAGE OF A MUNTZ-METAL STUD EXPOSED TO BILGE-WATER.

A Muntz-metal stud taken from the valve-chamber of a bilge donkey-pump on a Fleetwood and Belfast steamer, belonging to the Lancashire & Yorkshire and London & North Western Railway Companies, owing to the development of a flaw, showed, when broken through the flaw, an inner brassy core, while the outer portion was distinctly porous and coppery in appearance. When in position the stud and the brass seats to which it was secured were subject to the same action of sea- and harbour-water. The upper portion of the stud just above the flaw was also subject to the continual lifting and jarring of a small brass valve.

When sectioned longitudinally, polished and etched, the stud revealed the remarkable structure shown in Fig. 44, Plate 6, which is a full-size view of the stud (in three pieces). Fig. 45 is a transverse section of the stud at X X magnified four diameters. The light parts of the photograph (Fig. 44), marked "L," are the colour of ordinary brass, and are evidently portions of the original metal; whereas the dark parts, marked "D," are somewhat porous and coppery in appearance.

Chemical analyses of portions taken from the stud at the parts marked A, A1, B, C, and C1 gave the following results:—

Metal.	Sample taken from A Centre Core.	Sample taken from A 1 Outside Portion.	Sample taken from B.	Sample taken from C Centre Portion.	Sample taken from C 1 Outside Portion.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Copper	62·63	65·51	66·74	66·69	66·61
Zinc	37·09	33·10	32·42	32·44	32·85
Lead	0·56	0·66	0·51	0·51	0·51
Total . . .	100·28	99·27	99·67	99·64	99·97
	Taking the Copper as 100 in each sample, the Zinc varies as follows:—				
Copper	100	100	100	100	100
Zinc	59	51	49	49	49

From the analyses it is evident that the stud has lost zinc, owing most probably to the solvent action of the salt water; which of course accounts for its wastage.

The Note is accompanied by two photographs, from which Plate 6 has been prepared.

[APPENDIX.

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APPENDIX.

TABLE I.—CHEMICAL ANALYSIS AND TENSILE TESTS OF COPPER ROLLED ROD, AS SUPPLIED FOR LOCOMOTIVE FIRE-BOX STAYS.

No. 1.

	Per Cent.
Copper	99·76
Arsenic	0·20
Nickel	0·04
Sulphur	0·01
Phosphorus	0·01
Lead, Iron, Antimony	Traces
	100·02

Mark on Specimen.	Temperature of Test. Fahr.	Ultimate Tensile Strength.	Contraction of Area.	Elongation on 2 Inches.	Remarks.
	Degrees.	Tons per Sq. In.	Per Cent.	Per Cent.	
a	60	14·32	71·7	62	Normal rolled-copper-rod fracture.
b	,,	14·28	73·6	60	
c	,,	14·32	71·7	61	
2 *a*	200	12·72	73·6	54	Ditto.
b	,,	12·64	73·6	57	
c	,,	12·76	73·6	57	
3 *a*	300	13·08	69·8	40	Ditto.
b	,,	12·92	69·8	40	
c	,,	13·04	69·8	40	
4 *a*	400	10·80	75·4	54	Ditto.
b	,,	10·76	71·7	53	
c	,,	10·84	71·7	55	
5 *a*	500	9·88	61·5	48	Inferior rolled-copper-rod fracture.
b	,,	9·80	57·0	46	
c	,,	9·92	61·5	46	
6 *a*	600	8·59	35·9	36	Cast-copper fracture.
b	,,	8·75	36·1	33	
c	,,	9·76	27·3	23	
7 *a*	700	7·40	27·6	13	Ditto.
b	,,	7·40	15·0	10	
c	,,	7·32	27·6	13	
8 *a*	750	6·48	18·3	14	Ditto.
b	,,	6·64	21·5	15	
c	,,	6·40	21·5	12	

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TABLE II.—CHEMICAL ANALYSIS AND TENSILE TESTS OF COPPER-TIN ALLOY ROLLED ROD, AS SUPPLIED FOR LOCOMOTIVE FIRE-BOX STAYS.

No. 2.

	Per Cent.
Copper	97·07
Tin	2·91
Phosphorus	0·02
	100·00

Mark on Specimen.	Temperature of Test. Fahr.	Ultimate Tensile Strength.	Contraction of Area.	Elongation on 2 Inches.	Remarks.
	Degrees.	Tons per Sq. In.	Per Cent.	Per Cent.	
a	60	19·00	77·1	65	Normal rolled-copp rod fracture.
b	,,	18·99	78·6	64	
c	,,	18·72	78·1	61	
2 *a*	200	17·93	75·5	58	Ditto.
b	,,	17·98	78·6	59	
c	,,	17·81	75·5	58	
3 *a*	300	17·64	75·4	58	Ditto.
b	,,	18·29	77·2	58	
c	,,	17·73	75·5	54	
4 *a*	400	18·35	73·5	56	Ditto.
b	,,	18·12	71·7	53	
c	,,	18·48	73·6	57	
5 *a*	500	17·88	52·2	48	Inferior rolled-copp rod fracture.
b	,,	17·86	61·2	48	
c	,,	18·02	59·6	51	
6 *a*	600	15·80	36·4	32	Cast-copper fractur
b	,,	16·04	36·4	32	
c	,,	15·52	33·5	31	
7 *a*	700	14·48	36·9	30	Ditto.
b	,,	14·62	36·1	30	
c	,,	13·80	30·6	24	
8 *a*	750	12·68	38·2	33	Ditto.
b	,,	12·72	33·3	34	
c	,,		33·5	34	

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TABLE III.—CHEMICAL ANALYSIS AND TENSILE TESTS OF COPPER-ZINC ALLOY ROLLED ROD, AS SUPPLIED FOR LOCOMOTIVE FIRE-BOX STAYS.

No. 3.

	Per Cent.
Copper	60·23
Zinc	39·61
Iron	0·28
Manganese	0·03
Arsenic	0·10
Antimony	0·01
Lead and Phosphorus	Traces
	100·26

Mark on Specimen.	Temperature of Test. Fahr.	Ultimate Tensile Strength.	Contraction of Area.	Elongation on 2 Inches.	Remarks.
	Degrees.	Tons. per Sq. In.	Per Cent.	Per Cent.	
a	60	26·60	61·5	50	Normal rolled-brass fracture.
b	,,	26·53	58·9	50	
c	,,	26·55	59·3	51	
2 *d*	200	24·04	61·5	53	Ditto.
e	,,	23·96	67·8	53	
f	,,	24·08	65·8	55	
3 *a*	300	21·63	65·9	58	Ditto.
b	,,	21·71	57·2	53	
c	,,	22·45	67·7	57	
4 *a*	400	19·59	48·5	52	Inferior rolled-brass fracture.
b	,,	19·72	36·4	41	
c	,,	19·52	36·4	45	
5 *a*	500	16·23	41·2	41	Cast-brass fracture.
b	,,	16·03	39·6	41	
c	,,	15·48	27·0	27	
6 *a*	600	11·68	21·4	24	Ditto.
b	,,	10·69	26·4	27	
c	,,	10·92	27·6	25	
7 *a*	700	7·08	47·2	32	Ditto.
b	,,	7·32	49·7	46	
c	,,	7·36	49·7	33	
8 *a*	750	5·16	49·7	34	Ditto.
b	,,	5·00	47·2	32	
c	,,	5·12	47·2	32	

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TABLE IV.—CHEMICAL ANALYSIS AND TENSILE TESTS OF COPPER-ALUMINIUM ALLOY ROLLED ROD, AS SUPPLIED FOR LOCOMOTIVE FIRE-BOX STAYS.

No. 4.

	Per Cent.
Copper	92·91
Aluminium	7·13
	100·04

Mark on Specimen.	Temperature of Tests. Fahr.	Ultimate Tensile Strength.	Contraction of Area.	Elongation on 2 Inches.	Remarks.
	Degrees.	Tons per Sq. In.	Per Cent.	Per Cent.	
L	60	24·88	73·6	89	Normal rolled-bronze fracture.
M	,,	24·68	69·8	88	
S	,,	25·96	69·8	89	
2 L	200	23·32	65·8	81	Ditto.
M	,,	23·72	67·8	95	
S	,,	25·20	69·8	83	
3 L	300	22·28	67·8	95	Ditto.
M	,,	22·76	63·7	87	
S	,,	24·44	67·8	81	
4 L	400	20·64	54·6	74	Inferior rolled-bronze fracture.
M	,,	21·76	54·6	78	
S	,,	24·32	57·0	74	
5 L	500	15·12	30·6	39	Cast-brass fracture.
M	,,	15·68	27·6	31	
S	,,	20·40	33·5	38	
6 L	600	12·08	21·5	26	Ditto.
M	,,	13·56	27·6	29	
S	,,	14·92	21·5	22	
7 L	700	10·04	27·6	16	Ditto.
M	,,	9·32	27·6	16	
S	,,	12·56	21·8	14	
8 L	750	8·57	15·4	14	Ditto.
M	,,	9·20	15·0	14	
S	,,	11·04	11·8	10	

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TABLE V.—CHEMICAL ANALYSIS AND TENSILE TESTS OF MILD STEEL (BESSEMER) ROLLED ROD, AS USED FOR LOCOMOTIVE FIRE-BOX STAYS.

No. 5.

	Per Cent.
Silicon	0·05
Carbon, combined	0·13
Sulphur	0·03
Phosphorus	0·07
Arsenic	0·04
Manganese	0·48
Iron (by difference)	99·20
	100·00

Mark on Specimen.	Temperature of Test. Fahr.	Ultimate Tensile Strength.	Contraction of Area.	Elongation on 2 Inches.	Remarks.
	Degrees.	Tons per Sq. In.	Per Cent.	Per Cent.	
a	60	26·84	61·5	39	Normal mild-steel fracture.
b	,,	26·96	61·5	40	
c	,,	26·88	61·5	40	
2 *a*	200	25·92	63·7	31	Ditto.
b	,,	25·84	61·5	28	
c	,,	28·88	61·5	31	
3 *a*	300	30·20	52·2	22	Ditto.
b	,,	29·52	54·6	23	
c	,,	30·88	57·0	26	
4 *a*	400	31·65	54·3	24	Ditto.
b	,,	31·92	54·6	24	
c	,,	31·36	54·6	24	
5 *a*	500	33·16	52·2	26	Ditto.
b	,,	32·60	52·2	26	
c	,,	32·48	52·2	26	
6 *a*	600	29·80	61·4	34	Ditto.
b	,,	30·16	61·5	34	
c	,,	29·72	61·5	34	
7 *a*	700	26·76	65·8	31	Ditto.
b	,,	26·64	65·8	32	
c	,,	26·80	65·8	32	
8 *a*	750	25·36	67·8	31	Ditto.
b	,,	25·28	69·8	32	
c	,,	25·32	69·8	33	

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TABLE VI.—CHEMICAL ANALYSIS AND TENSILE TESTS OF SPECIAL COPPER ROLLED ROD, SUBMITTED FOR LOCOMOTIVE FIRE-BOX STAYS.

No. 6.

	Per Cent.
Copper (by difference)	99·89
Arsenic	0·01
Nickel	0·02
Phosphorus	0·08
Iron, Sulphur	Traces
	100·00

Mark on Specimen.	Temperature of Test. Fahr.	Ultimate Tensile Strength.	Contraction of Area.	Elongation on 2 Inches.	Remarks.
	Degrees.	Tons per Sq. In.	Per Cent.	Per Cent.	
a	60	17·48	77·1	38	Normal rolled-copper rod fracture.
2 *a*	200	14·48	78·9	27	Ditto.
3 *a*	300	15·16	78·8	31	Ditto.
4 *a*	400	14·52	77·1	27	Ditto.
5 *a*	500	13·12	80·4	25	Ditto.
6 *a*	600	11·52	75·4	31	Ditto.
7 *a*	700	9·92	75·4	33	Ditto.
7 *b*	700	9·96	78·6	32	
8 *a*	750	9·24	78·8	36	Ditto.

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TABLE VII.—TENSILE TESTS AT ELEVATED TEMPERATURES.

Average Results.

Reference Number.	Number of Tests Made.	Temperature of Tests. Fahr.	Ultimate Tensile Strength.	Contraction of Area.	Elongation on 2 Inches.	Reference Number.	Number of Tests Made.	Temperature of Tests. Fahr.	Ultimate Tensile Strength.	Contraction of Area.	Elongation on 2 Inches.
		Degrees.	Tons per Sq. In.	Per Cent.	Per Cent.			Degrees.	Tons per Sq. In.	Per Cent.	Per Cent.
1	3	60	14·31	72·3	61·0	4	3	60	25·17	71·1	38·7
,,	,,	200	12·71	73·6	56·0	,,	,,	200	24·08	67·8	36·3
,,	,,	300	13·01	69·8	40·0	,,	,,	300	23·16	66·4	37·7
,,	,,	400	10·80	72·9	54·0	,,	,,	400	22·24	55·4	75·3
,,	,,	500	9·87	60·0	46·7	,,	,,	500	17·07	30·6	36·0
,,	,,	600	9·03	33·1	30·7	,,	,,	600	13·52	23·5	25·7
,,	,,	700	7·37	23·4	12·0	,,	,,	700	10·64	25·7	15·3
,,	,,	750	6·51	20·4	13·7	,,	,,	750	9·60	14·1	12·7
2	3	60	18·90	77·9	63·3	5	3	60	26·89	61·5	39·7
,,	,,	200	17·91	76·5	58·3	,,	,,	200	26·88	62·2	30·0
,,	,,	300	17·89	76·0	55·7	,,	,,	300	30·20	54·6	23·7
,,	,,	400	18·32	72·9	55·3	,,	,,	400	31·64	54·5	24·0
,,	,,	500	17·92	57·7	49·0	,,	,,	500	32·75	52·2	26·0
,,	,,	600	15·79	35·4	31·7	,,	,,	600	29·89	61·5	34·0
,,	,,	700	14·30	34·5	28·0	,,	,,	700	26·73	65·8	31·7
,,	,,	750	12·70	35·0	33·7	,,	,,	750	25·32	69·1	32·0
3	3	60	26·56	59·9	50·3	6	1	60	17·48	77·1	38·0
,,	,,	200	24·03	65·0	53·7	,,	,,	200	14·48	78·9	27·0
,,	,,	300	21·93	63·6	56·0	,,	,,	300	15·16	78·8	31·0
,,	,,	400	19·61	40·4	46·0	,,	,,	400	14·52	77·1	27·0
,,	,,	500	15·91	35·9	36·3	,,	,,	500	13·12	80·4	25·0
,,	,,	600	11·10	25·1	25·3	,,	,,	600	11·52	75·4	31·0
,,	,,	700	7·25	48·9	37·0	,,	2	700	9·94	77·0	32·5
,,	,,	750	5·09	48·0	32·7	,,	1	750	9·24	78·8	36·0

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Discussion.

The President. The PRESIDENT was sure the members would join with him in according to the Author, an esteemed member of the Council, a hearty vote of thanks for the facts he had so carefully placed before the Institution. Although they occupied but a comparatively small space, those facts must be the result of a large amount of research, occupying much time.

The Author. The AUTHOR remarked he had little to add to the Paper, which, he thought, set forth fairly fully the reason for bringing the matter before the Institution. It was one of the most important questions in railway working, particularly in view of the large amount of work which modern locomotives had to perform in comparison with engines of earlier days, when pressures of 90 lbs. to 100 lbs. per square inch had been used. He had ordered the experiments to be made in consequence of the peculiar behaviour of a number of stays of metallic alloys, which the locomotive department of the London and North Western Railway had been asked to try. Although the alloys in question, when cold, would stand every mechanical test applied to them without failure, when they were used in fire-boxes they began to cause serious trouble. He had gone cautiously to work in the matter; but, as was mentioned in the Paper, after putting some of the bronze stays in a boiler, he had quickly been convinced that the best thing he could do was to take out every stay, because the stay-heads had begun to drop off whenever the engine worked hard —though shunting seemed to be performed without any trouble. He had become uneasy about the matter, and had thought it advisable to investigate the whole question of fire-box stays, in order to see if any material would answer better than the copper which had been employed for the purpose for so many years. The results of the tests showed that the best joints were obtained when the material of the stay was softer than that of the fire-box. To enable the members to see the results on a large scale, he had caused lantern-slides of the photographs in the Paper to be prepared, and he would ask Mr. Tipler, who had had charge of the experiments, to explain these slides as they were exhibited. When photographs of the mixtures of aluminium and copper were shown, it would be readily seen why, at a certain temperature, the strength of the material seemed to fail suddenly. The actual specimens

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of the materials tested were exhibited on the table. His thanks were due to Professor Unwin for having kindly exhibited his apparatus for testing hardness. The Author.

Mr. F. C. TIPLER then explained the photographs illustrating the Paper, slides of which were projected on the screen. Mr. Tipler.

Mr. JOHN A. F. ASPINALL remarked that the Paper dealt with a subject of immense importance at the present time in locomotive work. Early in the Paper it was mentioned how frequently stays had to be renewed, and he thought that pointed to the desirability of getting rid of the stay altogether, if possible. Engineers ought to look forward to a time when they would get rid of the rectangular fire-box and adopt something circular. So far as a locomotive as a whole was concerned, there could be no doubt that the only part of it which gave trouble was the boiler. As a machine and as a vehicle it gave no trouble whatever; it went on working from year to year, requiring only a little occasional repair. But the boilers were a source of everlasting trouble; and trouble in the boiler nearly always meant trouble in the fire-box. Therefore, if locomotive engineers could successfully devise some form of circular fire-box, it would prove to be one of the most important achievements of the time. Of course there were serious difficulties in getting, on a locomotive, a reasonably large fire-box having a corrugated flue. The results of the experiments described in the Paper tended to confirm results obtained by him some years ago at Horwich. His friend Mr. Hoy had made similar researches more recently, and the results also supported the Author's statements. He had no doubt the Author's opinion that the material used for the stay should be softer than that of the plate, really went to the root of the matter; one other point might be added, namely, that the plate should be reasonably hard. For many years a view had been held with which he entirely concurred, namely, that there should be a small proportion of arsenic in the copper, so as to give a harder plate. That enabled a harder stay to be used, having a longer life. Care must be taken not to have too hard a plate, otherwise it would crack against the flanges, and also between the tube-holes; then the remedy would be worse than the disease. With regard to steel stays, some of which the Author had exhibited, at one time he had used a large number, but they had been found to be not altogether satisfactory. There had been the same kind of trouble with breakage as the Author appeared to have experienced. While steel seemed to answer in engines worked at low speeds, such as were required for local traffic, it did not seem to answer well for other Mr. Aspinall.

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Aspinall. classes of engine. There could be no doubt that in some express locomotives the stays on the side of the fire-box which were near to the expansion angle-bar broke much more readily than those in other parts of the box. The fact was, that in the locomotive fire-box, with copper plate inside and steel plate outside, there were what might be termed two "drum-heads" tightly stretched and tied together by the copper stays. If on the outside of that there were an angle-bar which, though free to move, did so with a certain amount of friction, it could be imagined that if the engine lurched from side to side, the friction was increased, and the angle-bar pulled out the side plate. That additional pull would be quite sufficient to break a stay which had some little flaw in it. Undoubtedly, for that and other reasons a larger percentage of stays were broken upon express engines than upon engines working easy-going trains.

Mr. Dobson. Mr. J. M. DOBSON remarked that he had read the Paper with much interest, and considered that the Institution was greatly indebted to the Author for the clear manner in which he had dealt with the subject. Personally he was very glad the question had been opened up, as it was one which many engineers had been considering for a long time. The Paper dealt with three causes of failure of stays—wastage of heads, leakage, and breakage; and stated that the breakages were chiefly due to the expansion and contraction of the copper box. Of that there was no doubt; hence the great importance of obtaining the best and most suitable metal to allow the stays to bend in the manner required by such expansion. On the other hand, apart from the question of the metal of which the side stays are made, it was more than probable that they might also become leaky if proper provision were not made for the lifting of the roof of the copper box when the side plates and tube-plate were expanded by heat. If the roof could not rise, the flexure of the copper plates would naturally follow the top flange of the tube-plate—where the thickness was reduced—and the line of the top rows of stays in the side plates, enlarging the holes and causing leakage. The order given to the foremen that boilers were to be frequently and carefully washed out, was of the utmost importance, and insufficient attention to it was the cause of many of the troubles which occurred. Neglect of that procedure not only caused the stays in the lower portion of the box to become coated with scale, to become over-heated and to break as stated, but side stays in other positions were known to have failed for the same reason, and it had even rendered useless the most carefully-designed expansion-arrangement. He alluded to

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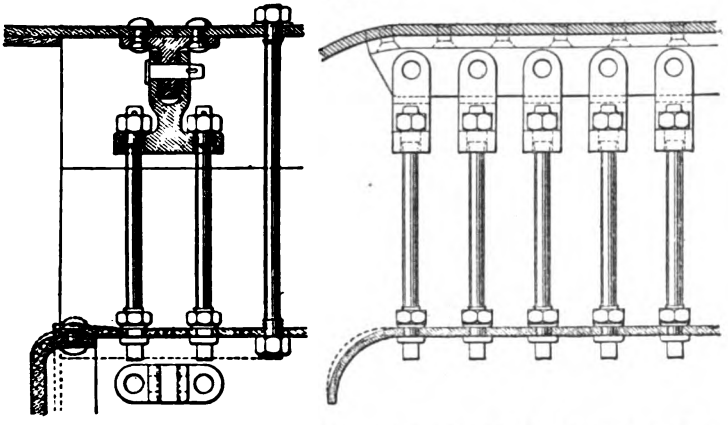
the question because within the past year his firm had had to deal with a case which proved its importance. In a number of engines built by a leading firm, and fitted with the Belpaire fire-box, expansion-links had been provided of a design which had been found to answer perfectly on other lines. The tube-plates in all those engines had had to be replaced, because they had utterly failed. Such had been the impression created by those failures that Belpaire boxes had been strongly reported against. In consequence, he had communicated with all the locomotive superintendents on the French lines and also with the locomotive superintendent of the Belgian State Railways, and their testimony, without exception, was in favour of the very fire-box and expansion-links—where they had been used—that were supposed to have

Mr. Dobbs.

Fig. 46.



caused the whole of the trouble. Why should that box and those stays answer on the French and the Belgian lines, and on many lines in this country, and yet fail elsewhere? He thought it would be apparent from *Fig. 46* that the cause was owing to the expansion-arrangement failing to work through the scale accumulated on account of insufficient washing. One of the advantages of the Belpaire box was that, as the top of the copper box was lifted by expansion of the copper tube-plate, if the roof stays were all rigid the expansion was transmitted to the flexible iron or steel shell; and in order to get over the difficulty of the want of flexibility in the portion of the roof which came nearer to the boiler-barrel, one, two, and sometimes three rows of expansion-links, as shown by the diagram, were introduced. In the engines referred to, those links had been attached to a strong T-bar

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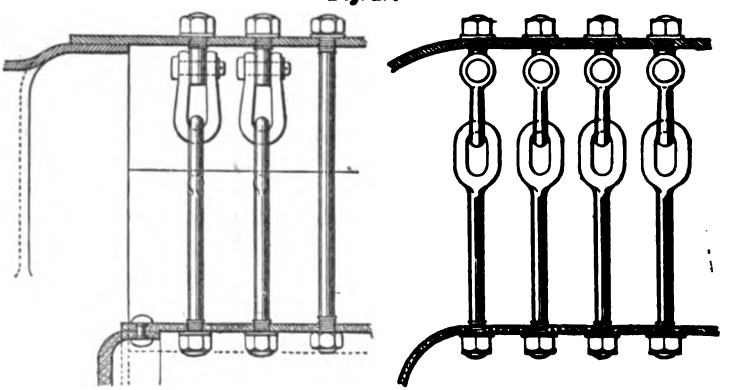
Jobson. riveted to the top shell, and if by any chance those links became jammed, which would result from a very small amount of incrustation, then what should be flexible became rigid, and thus what should be an additional source of safety was really a source of danger. An inquiry had been held, and it had been decided that the failure arose from the expansion-arrangements not having, from some cause or other, worked properly. That should teach engineers, in designing expansion-arrangements, to avoid anything likely to become fixed. A great many of the expansion-arrangements at present existing on engines, neat as they were in design, were likely to become a source of trouble if the scale were not properly removed by washing, or if they became jammed from some other cause. Mr. Hawkshaw and he were now adopting the expansion-arrangement shown in *Fig. 47*, by which the T-bar was got rid of,

Fig. 47.



and latitude was obtained. That arrangement had been found to answer perfectly on other lines; but even it might be choked if scale were allowed to accumulate. He referred to those failures of tube-plates with no desire to find fault, because there were so many circumstances and local conditions to be taken into account —such as the quality of the coal used, of the wood, and of the water—that the locomotive superintendent had to be ever on the alert, so that when the evil was traced to its true source remedies might at once be provided. Some time ago he had had an opportunity of carefully examining a copper fire-box completely coated with scale. It had been taken out of a 14-inch cylinder engine, which had been running at the Poynton and Worth colliery for 12 years. That copper fire-box had been attached by direct roof-stays to a semi-circular iron

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box, without any provision being made for expansion, a practice which experience had proved to be unwise. The box had shown very clearly how the tube-plate had expanded, there being about ⅜ inch difference between the level of the front and back plates; and although none of the roof- or side-stays had been broken, they had been bent considerably. That box was only a small one, 2 feet 10½ inches long by 2 feet wide. Undoubtedly, in a large box with stays of a similar design, the danger would be considerably increased, and would result in the cracking of the tube-plate, or breakage of the stays. During the past week he had inspected another copper box, taken out of a six-wheel-coupled tank-engine having 16-inch cylinders. It was coated to such a degree that the stays which were attached to the girders over the whole roof were bedded in one complete mass of scale, so that nothing could be moved. The Author stated that in the forty engines of the "Diamond Jubilee" class one stay for every 844 miles was replaced; while in the case of the ten locomotives of the "Alfred the Great" class each engine ran 17,000 to 43,000 miles without it being necessary to replace any stays. Before it would be possible to arrive at a comparison between those two classes of engines it would be necessary that the ten of the "Alfred the Great" class should have run 1,405,516 miles, whereas they had only accomplished 277,800 miles. On the other hand, while the copper-zinc alloy, with 40 per cent. of zinc, had given a very unsatisfactory result, the copper-zinc stays with 9 per cent. of the latter metal, had given a highly satisfactory result, as the Author admitted; and would compare not only with the copper stays of the seven six-wheel-coupled engines doing precisely similar work, but also with the stays of the forty engines of the "Diamond Jubilee" class; thus:—

Mr. Dobbs.

—	"Diamond Jubilee" Class (40). Pressure 200 Lbs. per Square Inch. Copper Stays.	Six-wheel-coupled Coal Engine. Pressure 150 Lbs. per Square Inch. Copper-Zinc Stays (9 per Cent. Zinc).	Six-wheel-coupled Coal Engines (7). Pressure 150 Lbs. per Square Inch. Copper Stays.
Average number of miles run by each engine .	140,552	284,978	Not given.
Average number of stays replaced in each engine . . .	166·5	51	Not given.
Frequency of renewal .	1 per 844 miles	1 per 5,588 miles	1 per 1,805 miles.
Average time of running	4½ years	10 years	10 years.
Number of broken stays in each engine . .	None recorded	14	Not given.

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Dobson. Taking this comparison into consideration, and seeing that the copper-zinc alloy (9 per cent. of zinc) had given such a good result, he thought it would be of great value if the Author would, if possible, give the information necessary to complete the comparison between the seven engines fitted with copper stays and the one engine with copper-zinc (9 per cent. zinc) which did precisely similar work; and also if he would say why he had not used that kind of stay, seeing that even in the case of the engine of the "Diamond Jubilee" class, while one copper stay failed in every 844 miles, the copper-zinc alloy (9 per cent. zinc) gave 6½ times the life, only one stay failing in 5,588 miles. Moreover, although the coal engine was only worked at 150 lbs. per square inch, it had been working for 10 years, while the "Diamond Jubilee" class of engine had only run for 4½ years; and although, during the 10 years, 14 stays had been broken in the coal engine, those replaced in the "Diamond Jubilee" engines had been for wastage of heads and leakage, and it would be interesting to know the percentage replaced on account of leakage. With regard to copper-manganese stays, the report from the Hungarian State Railways to the Railway Congress in Brussels in 1900, as also from the Northern Railway of France, was that they had given great satisfaction. On the Northern Railway of France copper-manganese stays had been found necessary, owing to the failure of copper stays in large boxes. The Southern Company of France had decided to use copper-manganese for their fast express engines which they had built in 1900. Of course that company had not yet had those engines running for a sufficiently long time to give a fair comparison; but copper-manganese stays had been used on the Hungarian State Railways since 1890, and it appeared to be of great importance, therefore, that the value of these stays should also be tested in England. In the Author's diagrams, *Figs. 15* and *15a*, the results showing for materials Nos. 1 to 6 the average tensile strength, and also the average elongations and contractions of areas at the different temperatures, were striking; but it must be remembered that the copper-zinc alloy (9 per cent. zinc) did not appear in the diagrams, for the reason given by the Author. Copper-zinc (40 per cent. zinc) was shown, but bearing in mind that the melting-point of zinc was 736° F., the result in regard to that material was not surprising. If the copper-zinc (9 per cent. of zinc) had been tested, no doubt the result would have been very different. The most satisfactory results of the tests shown by *Figs. 15* and *15a* were from mild steel. With regard to the riveting of stays, the forma-

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tion of a large head certainly affected the stay by increasing its thickness in the centre. The Author, in his conclusions, stated that it was necessary that the stays should be softer than the plates. He could understand why they should be as soft, but not softer; and if a very soft stay were used, he thought there would be a risk of the two plates coming together. He had had tests made more or less on the basis of the Author's, and the result had been that the plates had come together nearly $\frac{1}{32}$ inch, and the heads had had to be reduced. If the stays were made soft he did not see how the difficulty was to be met. He would be glad if the Author would say how he formed the heads, whether by hand hammers or by pneumatic hammers, and he would also be glad if, with his great experience, the Author would state what he considered should be the proportion of arsenic in the plates compared with that in the stays. In the analysis of the copper rod (No. 1, p. 107), where the ultimate tensile strength was 14·32 tons per square inch the amount of arsenic was given as 0·20 per cent., while in the analysis of the special copper rod (No. 6, p. 112), where the ultimate strength was 17·48 tons per square inch the arsenic was given as 0·01 per cent.; perhaps this was due to a clerical error. Again, the copper which gave what the Author called the "excellent joint," showed 0·55 per cent. arsenic for the plate and 0·34 per cent. for the stay. His firm specified 0·25 per cent. to 0·40 per cent. of arsenic for both plates and stays, but of course the tensile strength of the metal when cold was greatly affected by the method of treatment. Mr. Dobbie.

Professor W. C. UNWIN remarked that the Paper was extremely interesting, and was a typical account of a careful inductive investigation. The experiments were ingenious and conclusive. He had thought it might be useful to place on the table the apparatus with which the indentation-tests were made. He had concluded some time ago that, for certain purposes, it was of importance to determine the hardness of a material, quite independently of the qualities ordinarily tested. An indentation-test had been used for 50 years or more in testing hardness, but all the early indentation-tests had been made with a diamond-pointed tool, which had been caused to make an indentation by the blow of a falling weight. That had appeared to him to be a somewhat inconvenient mode of testing. In the first place, a diamond-pointed tool was difficult to keep in an exact form, and the measurements were not easy. Moreover, there was no graduation in the test if a falling weight were used. He had therefore contrived the little machine exhibited, in which the indentation was made in the ordinary statical testing-machine. The Professor Unwin.

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Professor Unwin. indenting-tool was simply a piece of steel of square cross-section, the four indenting edges of which could be used successively. The angle of the edge being a right angle, it was easy to grind it true; and as it was of very simple form it could be made excessively hard. The indenting-tool came down on top of a specimen ½ inch by ½ inch by 2 inches, and a vernier was provided for reading the depth of indentation.

Mr. Pilkington. Mr. WOODFORD PILKINGTON remarked that he would have been glad if the Author had tried some other stays, particularly some aluminium-copper alloys having aluminium as the base, as he was much interested in aluminium alloys. He had succeeded in obtaining specimens of aluminium as hard as Bessemer steel, and had submitted them to the War Office as "aluminium-steel"; and he hoped to increase the hardness until it approached that of the diamond.

Mr. Tritton. Mr. S. B. TRITTON remarked, in reference to the Author's statement that the effect of riveting copper alloys in copper plates had been to expand the hole in the plate at the base, that it would be interesting if any members who had made experiments on nutted stays with solid heads would give the results. He and his colleagues had made experiments with several fire-box stays with solid heads, but mechanical difficulties, such as the difficulty of knowing whether the thread was really tight in the plate, or whether the stay was bearing on the head, placed obstacles in the way of carrying the experiments forward. Both Lloyd's and the Board of Trade, however, offered a certain premium in their rules for stays fitted with nuts, that was, their constant for nutted stays was a more favourable one than that for stays merely screwed in and riveted over. It might be said that nutted stays in the fire-box of a locomotive would not answer, as they would burn away at once: but in many cases the roof-stays were nutted. It was true they were made of a different material, but the subject was worthy of investigation. All the experiments which had been made to show the breaking-down point at which screwed stays in fire-boxes failed, proved that a good head of some kind was an important element in the strength of the stay; and if a solid head of some form could be relied on, and could be mechanically effective, the subject might well be pursued further. Some of the diagrams in the Paper showed that the breaking-down point seemed to occur where the effect of riveting was most noticeable. In the case of many of the alloys, especially the harder alloys, the thread was much broken, and a predisposition existed for it to waste away under the action of the fire. In the stays of the softer alloys and copper that had not so much effect. It

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would be interesting to know whether the Author cupped his stay with a cupping-tool, or whether the stays were knocked down under the hammer. Investigation had shown that there was a considerable difference in the effect on the stay when so treated. Mr. Tritton.

Sir FREDERICK BRAMWELL, Bart, Past-President, remarked that many years ago an explosion had occurred in the boiler of H.M.S. "Thunderer," and that explosion had taken place where the front of the boiler and the flat surface had been stayed. The stays had been merely riveted, there being no nuts. The coroner's assessor, Mr. Fletcher, and himself, in the course of the enquiry had had made a mere flat box with sides 4 feet or 5 feet square and 4 inches or 5 inches apart, stayed together with stays such as had been in the real boiler, at about 6 inches or 8 inches apart. By hydraulic pressure that box had been tested to destruction, and the plate between the stays had been found to be bulged outward, so that the hole in the plate had become conical on the inside to such an extent as to entirely release the hold of all but one or two of the threads, which had then given way. The stays of some corresponding boilers under inspection and investigation had been provided with nuts; and in these boilers the fact of the hole in the plate becoming conical and thus releasing the threads of the stay, had not affected the part of the stay which passed through the nut. Sir Frederick Bramwell.

Mr. DRUITT HALPIN, referring to Mr. Tritton's remark as to Lloyd's and the Board-of-Trade rules allowing extra value for stays which were nutted, observed that this applied only to stays used in combustion-chambers and places of that kind, where the temperature was relatively moderate; and the circumstances were not parallel with those in the question under discussion, where temperatures running up to 2,500° F. and 3,000° F. were used. To put at the sides of a locomotive fire-box nuts of the kind used successfully in marine work under other circumstances would be a different matter. Mr. Halpin.

Sir FREDERICK BRAMWELL explained that he did not advocate the use of nuts in a locomotive fire-box, but had simply endeavoured to show how, in the absence of a nut, it was possible for the hole to be opened so as to release the threads of the stay. Sir Frederick Bramwell.

The PRESIDENT remarked he was not able to add any information with regard to locomotive fire-box stays, inasmuch as he had had no experience with them; but he would mention an experience he had had with studs of phosphor-bronze which had not been subjected to heat. These studs had been used for attaching the gun-metal face of a large waterworks valve to the cast-iron The President.

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President. body of the valve itself. They had been screwed into the face of the valve, passing through the cast-iron flange of the body of the valve, about 2 inches in thickness, and being then screwed up with nuts. After the bolts had been in for some little time they had been put into a tunnel, and subsequently several of them had been found to be broken in two. The valve had never been in use, and the door had not been put into position. It had been supposed that that might be due to a difference in contraction between the phosphor-bronze and the cast-iron. The studs had then been replaced by manganese-bronze studs. Again the same thing had happened, but to a less number of studs; and it had been found on examination of the bronze of which the studs were made that the mixture did not appear to be evenly distributed. But it was difficult to understand why they had failed, seeing that they had been doing no work and that the valve had never been in use: even when it was in use, the stress would be merely that of shearing. He mentioned the matter as showing how necessary it was to be cautious in making use of alloys.

The Author. The AUTHOR, in reply, remarked that, in the Paper, he had not gone at all into the question of roofing-stays, referred to by Mr. Dobson. But it was a wide question, and he hoped some other member of the Institution would contribute a Paper on it; if not, perhaps at a later date he might be able to give an account of the practice of the London and North Western Railway. In answer to other questions raised by Mr. Dobson, he might say that the average mileage of the seven six-wheel-coupled engines fitted with copper stays was 261,000 miles, as against a total mileage of 284,978 miles for the engine fitted with copper-zinc stays (9 per cent. of zinc). The good result shown by this alloy, he would again mention, had been obtained in a comparatively low-pressure boiler (150 lbs. per square inch) and slow-working engine; whether the material would answer any better than copper in a high-pressure boiler and heavily-worked passenger-engine could only be decided by trial. As regarded the amount of arsenic which should be present in the plate and stay, he had no doubt that 0·3 per cent. to 0·5 per cent. in the plate, and not more than half that quantity, if any, in the stay, would be found satisfactory. The subject of fire-box stays was of the utmost importance, as he could realize, having been in charge of the boilers of the London and North Western Railway for 30 years, and having under his charge 3,000 boilers containing 2,500,000 stays. The position was not exactly a bed of roses, and great care was needed in trying experiments with new alloys. With regard

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to aluminium alloys, if Mr. Pilkington would send him some of the aluminium-copper alloys he had referred to, he would gladly test them at the temperature at which they would have to work in a boiler, and would communicate the results to the Institution. If Mr. Pilkington would do that at once, he would take care that the results were added to the Paper, if so desired.[1] With regard to stays with solid heads, 40 years ago, when Mr. Ramsbottom had been at Crewe, many boilers had been stayed with iron stays with square heads inside the fire-box, but it had been impossible to keep them tight. That had been the case with engines working at 120 lbs. per square inch, not 200 lbs. or 210 lbs. as at the present time. The machine used at Crewe for heading stays was a pneumatic riveter of special construction. It worked well, and he would be glad to show it to any member who cared to go to Crewe. Formerly only a riveting-hammer had been used. He was very glad indeed if the Paper had been of any service to his brother members, and he would be pleased to help in any further investigations on kindred subjects. The Author.

The PRESIDENT remarked that the Institution would be much obliged to the Author if he would, as suggested, furnish the results of tests of the material referred to by Mr. Pilkington. The President.

Correspondence.

Mr. T. ANDREWS remarked that the enlargement of the crystal grains of the copper-aluminium rolled rod (Figs. 25 and 26, Plate 5) when submitted to a temperature below redness for a short time, was a matter of great practical importance, which doubtless had frequently led to an alteration of the original physical properties of some metals subjected to particular thermal conditions, or which, from accidental causes, had become heated beyond the normal conditions of service. Accidents had doubtless arisen from this cause. In a Paper[2] on "The Effect of Strain on Railway Axles," he had illustrated the effects of temperature on the crystalline structure and resistance of railway axles, and had further demonstrated, at comparatively low temperatures, the Mr. Andrews.

[1] The Author has not received from Mr. Pilkington the samples of his aluminium-copper alloys, and has therefore been unable to undertake the promised tests.—F. W. W. July, 1902.

[2] Transactions of Society of Engineers, 1895, p. 181.

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Andrews. change of crystalline structure brought about by thermal conditions. In the same Paper he had indicated the point of minimum resistance to flexure in railway axles, when stressed under varied conditions of temperature. He had also dealt with the matter in Papers[1] on "The Effect of Temperature on the Strength of Railway Axles." The effect of the increased size of metallic crystal grains which occurred, in some metals, even at comparatively low temperatures, has also been admirably illustrated by the recent researches[2] of Professor Ewing and Mr. Rosenhain. He had observed the same effect in various samples of wrought iron and steel which had been exposed to heat for various periods; and Professor Arnold had noticed the increase in the size of the crystal grains of iron under certain thermal conditions. With regard to the desirability of having locomotive boiler-stays relatively softer than the copper fire-box plate into which they were intended to be riveted, he thought it would be desirable that, as far as practicable, the coefficient of expansion of the metal used for stay-bolts should be equal to that of the fire-box plates which the stays were to connect. He felt that engineers were deeply indebted to the Author for his admirable research on a difficult yet highly important subject. He expected to publish shortly the results of a research he had made on stay-bolts for naval boilers, which he hoped might help to throw further light on the subject.

Mr. du Bousquet. Mr. DU BOUSQUET, of the Northern Railway of France, remarked that since the 1st April, 1901, the company had discontinued observation of the series of engines which formed the subject of Mr. Rodrigue's note in the *Revue Générale des Chemins de Fer* referred to by the Author, and in which the copper-manganese stays had always behaved well; therefore he could not give any later information in regard to them. The locomotives of the following series, Nos. 2,161 to 2,180, had been furnished, from the first, with copper-manganese stays in the upper three horizontal rows of the side plates and the back plate, the remaining stays being of copper. Each fire-box had 185 copper-manganese stays and 986 stays of copper; the boiler-pressure was 213 lbs. per square inch. Since these locomotives had been put into service, in March, 1898, they had covered a total mileage of 3,636,440 miles; the total stay-mileage for the copper-manganese was there-

[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 340; vol. xciv. p. 180; vol. cv. p. 161.

[2] Proceedings of the Royal Society, vol. lxvii. p. 112.

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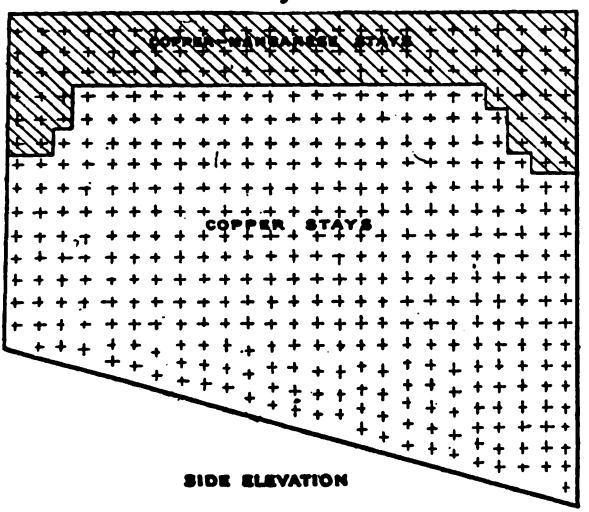
fore 3,636,440 × 185 = 672,741,400 stay-miles, and that for the copper 3,636,440 × 986 = 3,585,529,840 stay-miles. During the succeeding four years, six breakages of copper-manganese stays had occurred, being one for each 112,123,566 stay-miles; and 1,875 breakages of copper stays, or one for each 1,912,282 stay-miles. Comparison of these two figures showed that the breakages of copper stays were 58·6 times as frequent as breakages of copper-manganese stays, supposing the two materials to be placed under identical working-conditions; but such was far from being the case, because the copper-manganese stays had been placed where experience had shown that breakage was most likely to

Mr. du Bousquet.

Fig. 48.



occur. Additional trials had been made on two other series of compound locomotives having six wheels coupled. The fire-boxes of twenty-five locomotives (Nos. 3171–3195) had been constructed entirely with stays of copper-manganese, the diameter of the stays being 0·9 inch. Each fire-box contained 1,163 stays. The first of the engines had been put into service in March, 1901, and up to the 31st March, 1902, at which date the total mileage of these engines amounted to 711,786, only one broken stay had had to be replaced. In twenty similar engines (Nos. 3196–3215) the copper-manganese stays had been fitted in the upper three rows and in the corners of the side plates, as indicated by *Fig. 48*, there being 190 copper-manganese stays, and 973 copper stays per fire-box.

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Mr. du Bousquet.

These engines were of exactly the same class as Nos. 3171–3195, had similar boilers working at 213 lbs. per square inch, and did similar work. The first engine of the twenty had commenced to run in March, 1901, and their total mileage up to the 31st March, 1902, had been 435,448 miles, at which date no copper-manganese stay had failed, while 232 copper stays had had to be replaced. Owing to a misunderstanding, copper-manganese had not been used for the upper three rows of stays in the back plate; and in these three rows alone 137 copper stays had had to be renewed. The alloy in question had given rise to a slight difficulty in the formation of the stay-heads, but good results had been quickly attained in this respect.

Mr. Drummond.

Mr. D. DRUMMOND remarked that during the past two years locomotive engineers had been experimenting on a large scale with what were called "bronze stay-bolts," consisting of a mixture of copper, zinc, and iron, with results which were far from being satisfactory. Any composition which had a lower melting point than copper could not, in his opinion, be a satisfactory material for boiler-stays. The greatest wear and tear occurred at the heads of the stays in the fire-box. Many engineers made it a practice to roughly hammer down the heads, leaving a rough and uneven surface, whereby rapid wastage of the stay-head was caused. All stay-heads in the fire-box should not only be of large diameter and depth, but should be carefully smoothed over the surface with a cupped snap. If that was done there was, in his experience, little or no trouble from wastage by the burning away of the stay-heads. Great care should be given to see that the stays were a proper fit in the plates in the first instance. Leaky stays were due principally to careless workmanship. The remedy usually adopted was caulking the stay-heads; but no amount of caulking would make a stay tight if it was a loose fit in the copper plate to begin with, and the practice became an expensive and unsatisfactory attempt to prevent leakage in the fire-box. He made it a standing rule that no caulking was allowed. The system was to bore a $\frac{3}{16}$-inch hole in the end of the stay-head, having a depth equal to two-thirds of the thickness of the plate, and then to gently drift it with a tapered drift, so as to fill completely the threads in the copper plate by the expansion of the copper stay. This method yielded good results; in fact, all stays in new boilers on the London and South Western Railway were so treated. Another precaution he was adopting to prevent stays from leaking was to reduce the body of the stay so that all the threads inside the two plates were removed and the diameter was reduced $\frac{1}{16}$ inch by a regular taper to a point

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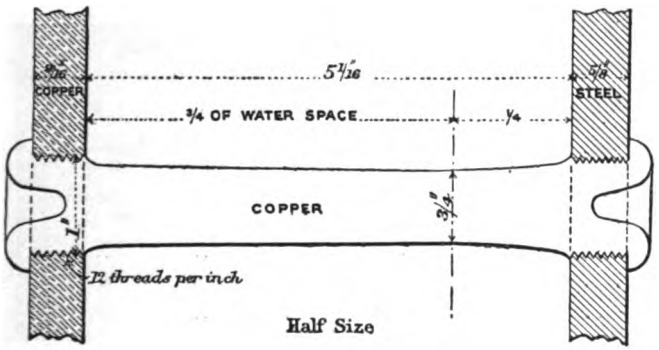
three-fourths of the length of the stay from the copper plate, so that the bending point due to the expansion of the copper box took place as far away from the copper plate as possible (*Fig. 49*). He agreed with the Author entirely that soft copper was the most suitable and reliable material for staying locomotive boilers; and Mr. Drummond.

Fig. 49.



he was also of opinion that the temperature in the fire-box, when engines were hauling trains weighing 350 tons to 400 tons at 50 miles per hour, was over 2,000° F. It was no uncommon thing to see the cast-iron door-scoop melting freely when an engine was doing its best.

Mr. Samuel W. Johnson considered that the Author had dealt with a difficult subject in both a practical and a scientific manner. During the past few years the increased traffic on railways had called for a service of passenger and goods trains of greater weight, and run at higher speeds, than formerly; necessitating the use of larger and more powerful engines, with boilers worked at pressures up to 200 lbs. per square inch. These higher pressures had entailed a proportionate increase in the thickness of steel and copper plates used in the construction of the boilers. To meet these altered conditions, and also to allow for the low elastic limit of ordinary copper stay-bars at high temperatures, and for the difference between the expansion of the steel shell-plates and that of the copper plates of the fire-box, it had been thought desirable to try to find a better quality of copper or copper alloy, which should be stronger and tougher, unbreakable in working, and have a higher elastic limit than was obtainable with ordinary commercial copper. To this end many manufacturers of copper had submitted various samples of superior copper and also of copper alloys, which had been under trial in Great Britain, in the Mr. Johnson.

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f. Johnson. Colonies and on various foreign lines. He had made a large number of experiments at Derby for the purpose of ascertaining the value of various kinds of copper and copper alloys for fire-box stays. Some of the stays made of these alloys had been working between 5 and 6 years, and were still at work. To a large extent the results of the experiments corroborated the statements made by the Author. In the following Table were given the chemical analyses of six materials

ANALYSES OF LOCOMOTIVE FIRE-BOX STAYS.

Description.	1 Arsenical Copper.	2 Arsenical Copper.	3 Copper-Zinc Alloy.	4 Copper-Zinc Alloy.	5 Copper-Nickel Alloy.	6 Deoxidised Copper containing Phosphorus.
Copper . . .	99·18	99·42	61·50	63·23	95·51	99·84
Silver . . .	Trace	..	..	..	..	Trace
Lead . . .	Nil	0·06	0·12	0·09	Nil	Nil
Bismuth . .	0·003	0·012	Mere trace	..	..	0·001
Tin	Trace	Nil	Nil	..	..	Nil
Antimony . .	0·019	0·013	..	..	..	0·005
Arsenic. . .	0·520	0·27	..	..	..	0·007
Iron . . .	Trace	0·022	0·27	0·29	1·59	Nil
Aluminium .	..	0·008				
Manganese . .	..	..	0·52	0·17	0·02	
Zinc . . .	Nil	Trace	37·47	36·02	Nil	Nil
Nickel . . .	0·088	0·04	0·20	0·19	2·91	0·16
Silicon . . .	..	Nil	Nil	Nil or mere trace	0·13	Nil
Oxygen[1] . .	0·124	0·108	..	..	..	0·009
Phosphorus .	..	Nil	Nil	..	..	0·103
Sulphur . .	0·005	..	..	..	..	Nil
	99·939	99·953	100·08	99·99	100·16	99·981

to which he had paid particular attention. The Tables on pp. 131–133 showed the mechanical tests of these materials, as supplied by the makers, made at the ordinary atmospheric temperatures, at 370° F., at 400° F., and at 600° F. In all cases there was a reduction in the tensile strength, and in the ductility, with rise of temperature. This decrease of strength at the higher temperatures was least marked in the case of the copper-nickel and copper-zinc alloys Nos. 3, 4,

[1] Including hydrocarbons.

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TENSILE TESTS OF LOCOMOTIVE FIRE-BOX STAYS AT VARIOUS TEMPERATURES.

Diameter of each test-piece, 0·798 inch. Sectional area of ditto, 0·5 inch.
Length of ditto, 2 inches.

Date Tested. 1881.	Test Bar Number.	Elastic Limit. Tons per Square Inch.	Maximum Stress. Tons per Square Inch.	Elongation Per Cent.	Contraction at Fracture. Per Cent.	Stress at Moment of Fracture. Tons per Square Inch.	Remarks.
				No. 1 Copper-rod.			
30 Apr.	35,161	4·3	15·3	48·5	57·85	30·8	Tested cold.
	35,162	4·0	15·3	51·0	57·03	31·2	
	Mean	4·15	15·30	49·75	57·44	31·00	
2 May	35,163	4·0	12·4	52·1	59·14	27·0	Tested at 370°. Loss in tensile strength at 370° = 19·9 per cent.
	35,164	3·3	12·2	51·5	60·41	29·0	
	Mean	3·65	12·30	51·80	59·77	28·00	
19 July	36,096	3·4	12·3	52·6	60·26	26·4	Tested at 400°. Loss in tensile strength at 400° = 19·9 per cent.
	36,097	3·3	12·2	52·4	59·14	25·7	
	Mean	3·35	12·25	52·50	59·70	26·05	
	36,098	3·0	10·8	48·7	53·69	20·6	Tested at 600°. Loss in tensile strength at 600° = 29·4 per cent.
	36,099	3·4	10·8	48·7	53·86	20·6	
	Mean	3·20	10·80	48·70	53·77	20·60	
				No. 2 Copper-rod.			
13 May	35,243	3·5	14·2	55·0	60·73	30·6	Tested cold.
	35,244	3·5	14·0	55·6	60·73	30·6	
	Mean	3·50	14·10	55·30	60·73	30·60	
	35,245	2·5	11·3	55·3	63·96	26·4	Tested at 370°. Loss in tensile strength at 370° = 19·8 per cent.
	35,246	2·5	11·3	55·0	63·51	26·1	
	Mean	2·50	11·30	55·15	63·73	26·25	
22 July	36,100	2·7	11·5	54·5	62·75	25·5	Tested at 400°. Loss in tensile strength at 400° = 18·8 per cent.
	36,101	2·7	11·4	55·9	63·81	26·2	
	Mean	2·70	11·45	55·20	63·28	25·85	
	36,102	2·5	9·65	37·7	35·66	14·0	Tested at 600°. Loss in tensile strength at 600° = 31·6 per cent.
	36,103	2·5	9·65	37·0	34·65	13·3	
	Mean	2·50	9·65	37·35	35·15	13·65	

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Johnson.

TENSILE TESTS OF LOCOMOTIVE FIRE-BOX STAYS AT VARIOUS TEMPERATURES—*continued.*

Diameter of each test-piece, 0·798 inch. Sectional area of ditto, 0·5 inch.
Length of ditto, 2 inches.

Date Tested. 1901.	Test Bar Number.	Elastic Limit. Tons per Square Inch.	Maximum Stress. Tons per Square Inch.	Elongation Per Cent.	Contraction at Fracture. Per Cent.	Stress at Moment of Fracture. Tons per Square Inch.	Remarks.
			No. 3. Copper-zinc alloy.				
3 Aug.	36,123	6·8	21·0	67·2	65·30	53·5	Tested cold.
	36,124	6·8	21·2	67·2	65·30	53·5	
	Mean	6·80	21·10	67·20	65·30	53·50	
9 Aug.	36,125	6·8	19·4	75·0	63·81	47·2	Tested at 370°. Loss in tensile strength at 370° = 7·8 per cent.
	36,126	6·8	19·5	76·5	63·81	47·8	
	Mean	6·80	19·45	75·75	63·81	47·50	
8 Aug.	36,127	6·8	19·2	76·5	63·05	45·9	Tested at 400°. Loss in tensile strength at 400° = 8·3 per cent.
	36,128	6·8	19·5	72·6	63·81	47·5	
	Mean	6·80	19·35	74·55	63·43	46·70	
	36,129	6·5	17·2	61·8	51·44	27·4	Tested at 600°. Loss in tensile strength at 600° = 18·9 per cent.
	36,130	6·6	17·0	63·5	50·74	26·8	
	Mean	6·55	17·10	62·65	51·09	27·10	
			No. 4. Copper-zinc alloy.				
10 May	35,225	6·0	20·8	72·65	68·89	56·4	Tested cold.
	35,226	6·0	21·0	72·65	69·17	58·4	
	Mean	6·00	20·90	72·65	69·03	57·40	
8 May	35,227	6·0	18·5	73·44	65·59	46·5	Tested at 370°. Loss in tensile strength at 370° = 11·5 per cent.
	35,228	6·0	18·5	73·44	65·59	46·5	
	Mean	6·00	18·50	73·44	65·59	46·50	
25 July	36,106	6·0	18·8	76·6	66·76	48·2	Tested at 400°. Loss in tensile strength at 400° = 10·3 per cent.
	36,107	6·0	18·7	75·0	65·74	46·8	
	Mean	6·00	18·75	75·80	66·25	47·50	
4 Nov.	37,064	5·8	16·0	59·8	46·61	24·3	Tested at 600°. Loss in tensile strength at 600° = 23·4 per cent.
	37,065	5·9	16·0	57·5	43·45	23·8	
	Mean	5·85	16·00	58·65	45·03	24·05	

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TENSILE TESTS OF LOCOMOTIVE FIRE-BOX STAYS AT VARIOUS TEMPERATURES—*continued*.

Diameter of each test-piece, 0·798 inch. Sectional area of ditto, 0·5 inch. Length of ditto, 2 inches.

Date Tested. 1901.	Test Bar Number.	Elastic Limit. Tons per Square Inch.	Maximum Stress. Tons per Square Inch.	Elongation Per Cent.	Contraction at Fracture. Per Cent.	Stress at Moment of Fracture. Tons per Square Inch.	Remarks.
				No. 5. Copper-nickel alloy.			
1 June	35,505	12·8	18·9	43·4	74·87	47·6	Tested cold.
	35,506	12·8	18·9	43·4	76·80	51·7	
	Mean	12·80	18·90	43·40	75·83	49·65	
3 June	35,507	12·5	16·5	40·7	76·4	46·6	Tested at 370°. Loss in tensile strength at 370° = 13·7 per cent.
	35,508	12·4	16·1	89·6	76·4	46·6	
	Mean	12·45	16·30	40·15	76·40	46·60	
3 June	35,634	12·3	15·8	40·6	76·8	43·1	Tested at 400°. Loss in tensile strength at 400° = 16·7 per cent.
	35,635	12·4	15·7	40·3	75·6	41·0	
	Mean	12·35	15·75	40·45	76·20	42·05	
25 July	36,285	11·5	14·8	35·9	71·76	35·5	Tested at 600°. Loss in tensile strength at 600° = 22·7 per cent.
	36,286	11·4	14·4	35·5	70·14	33·5	
	Mean	11·45	14·60	35·70	70·95	34·50	
				No. 6. Copper rod.			
23 Sept.	36,628	16·2	17·5	40·0	76·72	51·7	Tested cold.
	36,629	16·3	17·4	41·2	77·08	50·0	
	Mean	16·25	17·45	40·60	76·90	50·85	
26 Sept.	36,630	14·6	14·8	38·0	78·26	45·9	Tested at 370°. Loss in tensile strength at 370° = 15·2 per cent.
	36,631	14·7	14·8	38·3	77·80	45·0	
	Mean	14·65	14·80	38·15	78·03	45·45	
27 Sept.	36,632	14·5	14·5	37·0	78·26	48·6	Tested at 400°. Loss in tensile strength at 400° = 16·6 per cent.
	36,633	14·3	14·6	38·0	77·92	48·2	
	Mean	14·40	14·55	37·50	78·09	43·40	
27 Sept.	36,634	11·0	12·1	38·8	74·62	35·4	Tested at 600°. Loss in tensile strength at 600° = 30·1 per cent.
	36,635	11·1	12·3	39·8	75·12	36·2	
	Mean	11·05	12·20	39·30	74·87	35·80	

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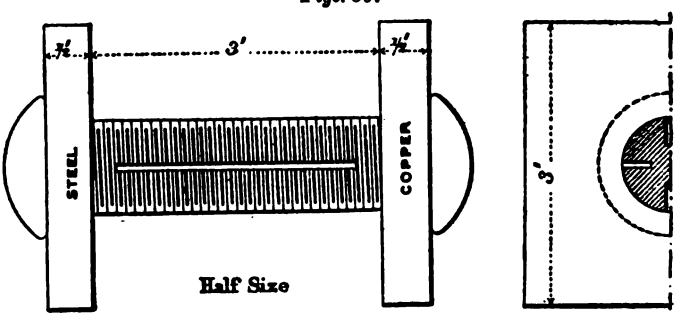
Johnson. and 5, No. 3 suffering a reduction of only 18·9 per cent. at 600° F. No. 1 copper containing arsenic and oxygen and the purer No. 2 copper containing arsenic and traces of other substances, lost about 30 per cent. of their strength at 600° F. No. 6 was a deoxidized copper containing phosphorus. It was remarkably pure, and at ordinary temperatures had a tensile strength of 17½ tons per square inch, with an elongation of over 40 per cent. All the copper-zinc stays he had tested were very tough and strong, and never broke when in the fire-box. However, after working for some time they gave more trouble from leakage than did ordinary copper stays, especially when the water used was bad. The stay-heads of these alloys also wore away somewhat more than copper ones. The tests of deoxidized copper containing phosphorus and of the copper-nickel alloy (Nos. 5 and 6) fulfilled all the requirements for a satisfactory and reliable stay material; but he had not had them at work for a

Figs. 50.



sufficient length of time to prove their actual value in practice. The breakage of fire-box stays resulted more from the strains set up by differences of expansion and by relative movement of the fire-box and boiler-shell than from the actual stresses they were subjected to by the steam-pressure. In order to make the stays more flexible, the material used should be as strong as possible, so as to admit of the stays being of comparatively small diameter. He had also used a large number with grooves cut in them, as shown in *Figs. 50*, to increase their flexibility. The grooving somewhat reduced the section and thereby weakened the stays, as was shown by the following Table, which gave the results obtained with stays of all six of the materials mentioned on p. 130. These tests had been made with stays screwed and riveted into copper and iron plates as in a boiler fire-box. Owing to increasing steam-pressures, higher fire-box temperatures, larger fire-boxes, and heavier work, the stays of locomotive fire-boxes were very severely

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Mr. J

TESTS OF SCREWED AND RIVETED COPPER AND BRONZE FIRE-BOX STAYS.

(Screwed stays, 1 inch in diameter, having eleven threads per inch.)

No. of Material Table, p. 139).	Test Bar Number.	Permanent Elongation commenced.	Load to Produce $\frac{1}{10}$ inch Permanent Elongation.	Maximum Load.	Total Elongation after Failure.	Temperature of Test, Fahr.	Remarks.
		Tons.	Tons.	Tons.	Inch.	Degrees.	
1	37,081–3	4·16	4·86	7·90	$1\frac{7}{32}$	400	Plain stays.
	37,084–6	3·83	4·46	7·16	$\frac{13}{16}$	400	With saw grooves.
	Loss in tensile strength from grooving = 9·4 per cent.						
2	37,087–9	4·56	5·00	7·53	$1\frac{11}{32}$	400	Plain stays.
	37,090–2	4·26	4·63	6·70	$\frac{27}{32}$	400	With saw grooves.
	Loss in tensile strength from grooving = 11·0 per cent.						
3	37,105–7	5·20	6·10	10·80	$1\frac{5}{16}$	400	Plain stays.
	37,108–10	4·56	5·33	9·23	$\frac{7}{8}$	400	With saw grooves.
	Loss in tensile strength from grooving = 14·5 per cent.						
4	37,099–01	5·50	6·00	12·16	$1\frac{3}{4}$	400	Plain stays.
	37,102–4	4·83	5·46	10·56	$1\frac{1}{4}$	400	With saw grooves.
	Loss in tensile strength from grooving = 13·1 per cent.						
5	37,093–5	7·90	8·63	9·96	$\frac{31}{32}$	400	Plain stays.
	37,096–8	7·06	7·63	8·86	$\frac{31}{32}$	400	With saw grooves.
	Loss in tensile strength from grooving = 11·0 per cent.						
6	37,637–9	9·30	9·66	9·76	$1\frac{1}{16}$	400	Plain stays.

NOTE.—The figures given are, in each instance, the mean of three tests. Each stay broke in the middle.

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Johnson. strained and heated in the more modern types of locomotive; and this fact was now calling the serious attention of locomotive engineers to the question of staying, and causing them to look out for a more suitable material than commercial copper. As the Author pointed out, it was not merely a question of ductility and strength. The material must stand the action of heated gases without suffering corrosion; its coefficient of expansion must be such that it expanded and contracted with the copper box into which it was screwed so as not to set up leakage; it must be soft enough to stand riveting without damaging the threads in the copper plates and sufficiently flexible to stand the differential expansion of the box and shell without fracture. Copper more or less pure had so far served remarkably well, but it remained to be seen which alloy of that metal was really the most suitable for staying locomotive fire-boxes.

Mr. Jordan. Mr. W. LEIGHTON JORDAN remarked that the diagrams and explanations given by the Author showed that the copper alloys proved less suitable than copper for fire-box stays, thereby appearing at first sight to confirm reasons he had given elsewhere for expecting pure metal to be more likely to adapt itself to changes of temperature than alloys; but it appeared to him quite possible that in the special cases mentioned the alloys had never had a fair chance as regarded the question of withstanding injury by changes of temperature, as the screw-joints had perhaps already been damaged in the process of hammering down their heads before the fire-boxes began to be used. The evidence might, in fact, be adduced to support the idea that in hammering down the head of the stay the screw-joint was improved in the copper stay, and more or less damaged in those of copper alloys. Both of the above actions might be effective in the question, independently of the effects due to the relative quantities of arsenic in the plates and in the stays. Perhaps, in further elucidation of the subject, the Author might be able to add an analysis of each of the two metals in Fig. 30; that was, an analysis of the metal of the fire-box and of the mild steel stay shown in that figure.

Mr. Joy. Mr. DAVID JOY mentioned that when in charge of the locomotives of the Oxford, Worcester and Wolverhampton Railway in 1855 he had met with the following instance of peculiar corrosion of fire-box stays. Water containing 84·14 grains of magnesium sulphate per gallon, but looking bright and pellucid, had played strange havoc with the upper rows of the fire-box stays, corroding them close to the iron outer plate of the fire-box as if they had been cut round with a tool, till they broke without any warning. The usual

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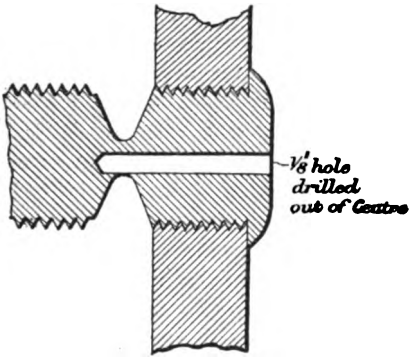
test of tapping the head with a hammer had indicated no difference in sound till breakage of a whole row occurred. He had concluded that this corrosion was due to the water setting up galvanic action between the two metals. There had been no remedy but to detect the damage at an early period, for there had been no regularity in its appearance. The treatment resorted to had been to drill a $\frac{1}{8}$-inch hole in all stays of the upper three rows, a little below the centre of each stay (*Fig. 51*). The corrosion which took place equally all round ate into the test-hole, and produced a small leak before the stay was corroded quite through, and so gave warning to remove the stay and examine those around it.

Mr. Jo

Fig. 51.



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Mr. F. A. LART thought it was a pity that the Author, with his extensive experience, had not dealt with the whole question of fire-box staying, according to the title of the Paper, rather than with water-space stays only. The Author's conclusion as to copper, of somewhat milder quality than the copper box itself, being generally the most suitable material for water-space stays would probably not be widely disputed; and his experiments, as far as they went, showed that no really satisfactory copper alloy had been found to supersede copper. As far as Mr. Lart knew, also, all the copper-alloy stays proved, in the long run, to be more expensive than copper itself. Although at present copper was very expensive, its cost was always recoverable without much loss, and its chief defects were undoubtedly its low tenacity and elastic limit. In these respects most of the copper alloys had the advantage. The Author did not deal with the riveting of stay-heads, but the method of effecting this probably had much to do with the life of the head and of the stay itself, and with the efficiency of the screwed joint. He did not consider that the practice followed at Crewe of riveting over the heads by means of a special pneumatic tool designed there, combined with a holder-on at the back, was satisfactory; because too much work was put on to the stays in the least efficient manner, namely, by a

Mr. Lart.

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Mr. Lart. multitude of light strokes. This hardened the stay-head, and would no doubt have a tendency in a copper alloy to set up crystallization, with proportionate hardness and brittleness which the subsequent heating would possibly not neutralize. The best riveting, he thought, was secured by a few heavy and effective blows from a couple of 7-lb. or 8-lb. hammers, followed by a couple of lighter caulking-hammers and a light single-handed snap. This resulted in the stay-head being, first, well spread into the hole, and, secondly, closed tightly and neatly down on to the plate. The stay should of course be well held up throughout. In the fire-box especially it seemed advisable to rivet the head down on to the plate as closely as possible, to prevent the fire from penetrating under the head and eating it away, and so getting at the thread and eating into the joint also; and it was advantageous to smooth the head by snapping so as to prevent it from being burnt and cut away by the action of the fire. The value of a stay-head, such as an ordinary rivet-head, as a holder seemed to be nil, its use being solely to protect the thread and joint. All copper alloys were unsatisfactory in respect of riveting over to form a head, and to expand the stay into the plate. With a 1-inch copper stay a finished snapped head $1\frac{1}{2}$ inch in diameter could well be got; whereas, he had found that no alloy would give more than $1\frac{3}{16}$ inch, and then the head had been cracked and pieces flaked off all over, being started by the run of the threads. Objection to snapping was sometimes raised on the ground that it loosened the stay in the hole after riveting, but this seemed impossible if the snapping was lightly done as it should be. From observation of all classes of work in British locomotive shops and elsewhere, it seemed that on the whole snapping was preferred, and almost always in the case of copper alloys. The stay-heads in Plate 5 of the Paper showed clearly that they had not been properly closed on to the plate, and Figs. 40 and 41 showed, he thought, that wastage and scouring of the head and plate had been assisted by the Author's method of leaving the threads standing above the plate and exposed to the heat. In Fig. 42 the stay-heads were much more workmanlike, and that on the steel plate was an ideal head. The practice of drilling stays, either for leakage or drifting, had not much to recommend it. The small detector-hole usually became quickly plugged up with scale when the stay was cracked or broken, and thus, if the line of fracture happened to communicate with the detector-hole, prevented any signs of leakage. A drifting-hole, usually one-third the diameter of the stay, was

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perhaps a source of weakness somewhat analogous to the drilling of a stay-head for removal; while the practice of merely drifting a stay without riveting it over seemed a fatal one. In the Author's illustrations it would be noticed, though it might be only a coincidence, that only the drifted stays showed cracked threads in addition to wasted threads. The mere fact of drifting a naturally hard alloy, made harder by riveting, might render the head liable to crack, and in the case of a copper stay there would be a tendency to spread the hole, at least in the copper plate. The wastage of threads, besides being due to the constant breathing of the stay in its hole and the searching action of the fire and water, might possibly also be due to galvanic action set up by acids in the water or even by the coarse lubricating-oil used in tapping the holes, which, he had often noticed, left the copper plate clean and scoured wherever it had rested. As to the loss of strength and ductility in all stays under heat, although no doubt this took place, it was probably questionable whether the artificial conditions of the hot-air or oil-baths were quite analogous to those of a stay fiercely heated by fire at one end and simultaneously quenched (although also heated) by water. The molecular disturbance or red-shortness caused by the one would undoubtedly be completely neutralized, at least in the body of the stay, by the quenching action of the other. Therefore the loss of strength would perhaps be inappreciable under these conditions, at least in copper stays. The greater tendency to red-shortness in copper alloys, of whatever mixture, was another defect in this respect, although their actual behaviour was mysterious. He had made some time ago the following rough experiments with a view to ascertain as far as possible the deteriorating effect of heat on a well-known copper alloy under circumstances which might, or might not, be considered as somewhat approximate to actual working-conditions:—Ten lengths of the rolled stay material had been taken promiscuously and turned down from $1\frac{1}{16}$ inch in diameter to $\frac{3}{4}$ inch diameter on a 3-inch test-length. Two lengths had been set aside in that condition: two had been heated simultaneously in a gas rivet-oven to a "black" heat, withdrawn together, and one of them plunged immediately into boiling water till completely quenched, the other being allowed to cool on the wooden floor near the oven. Two others had been similarly heated together to a very dull red and withdrawn together, one being then immediately quenched in boiling water, and the other allowed to cool, as before. The next two had been heated to a red heat and similarly treated. The last two had been heated to a bright red, withdrawn together and quenched and cooled, respec-

Mr. Lat

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Mr. Lart. tively, as before. All the heated samples, when withdrawn, had been coated lightly or heavily, according to the heat they had been subjected to, with a white deposit of zinc, which had sweated out. All the ten samples had been tested together a few hours afterwards. The maximum and minimum results had been as follows, the limits of elasticity not having been noted:—ultimate tensile strength 22·148 tons and 21·35 tons per square inch; elongation, 68 per cent. and 62 per cent.; reduction of area at fracture, 48 per cent. and 44 per cent. All the fractures had been normal and good. In no case, except as to one breaking load, had the untreated samples given the maximum results quoted. He thought these results showed that it was difficult to estimate with any accuracy the effect of heat on such alloys. There was no questioning their physical value in the natural state, but somehow their efficiency as water-space stays was decidedly doubtful. The practice of deeply nicking with saw-cuts the body of a stay might add flexibility, but it certainly greatly reduced its strength, and was dangerous by reason of the tendency the stay had to twist on its axis and miss the threads in the opposite plate when being screwed in, if it was a properly tight fit in the holes. Also there was the danger, when these stays were drilled with detector-holes, of running them into the saw-cuts; and he had seen a boiler leaking like the rose of a watering-can at 50 per cent. of the stays under its own full head of water when preparing for testing, so that half the stays in the box had had to be at once renewed before any testing was possible. As the Author had remarked, it was highly desirable in the case of a copper box, and copper or copper-alloy stays, to put the stays in from the inside of the box wherever possible, in order to avoid the threads being turned down by previously passing through the harder steel plate. With wrought iron or steel stays the reverse method was preferable. This made a good deal of difference in the fit of the stay in the holes. Wrought iron or steel stays did not seem satisfactory in copper boxes by reason of the galvanic or chemical corrosion set up between the metals. He had heard that some experiments at Derby had shown a Midland copper box to expand $\frac{5}{8}$ inch upward in working, so that, presumably, half-way up the rise would be $\frac{5}{16}$ inch; these seemed serious distances. As the Author had pointed out, breakage of stays usually occurred in one particular locality, namely, diagonally downward from the top front or back corners in the side plates, showing that there was considerably more movement in the top of the box than in the lower parts. Much of this no doubt depended on the system of

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roof-staying, which was not touched on in the Paper; otherwise he would have liked to hear something of the comparative advantages of rigid or flexible roof-staying and the various methods adopted. Mr. La.

Mr. W. P. MARSHALL remarked, in reference to the failure of fire-box stays, that an important point requiring consideration was the over-heating of the copper fire-box that arose from the imperfect supply of water to it in the prevailing mode of feeding locomotive boilers. The feed-water was in general practice delivered in the middle of the boiler-barrel, and only reached the fire-box by traversing the narrow water-space between the inner and outer shells, in which it was obstructed by the numerous stays and also by the passage in the opposite direction of the steam generated in the fire-box. This arrangement, though sufficing in the earlier smaller boilers, had, from the great increase of size in modern engines, become quite insufficient; and instead of having solid water in contact with the fire-box sides, the supply of water was liable to become so deficient that the copper plates became over-heated to such an extent as to bulge out between the stays. The holes into which the stays were screwed then became stretched in diameter, slacking the hold of the screw-threads; and the hold of the stays was further reduced by their riveted heads getting partly burnt away, until at last the fire-box plate was stripped off the stays and an explosion of the boiler took place. A remarkable instance had occurred in the Knottingley accident (11 March, 1901), when the boiler had been projected like a rocket to a distance of 170 feet, as a result of the sudden liberation of steam; the left side of the copper box being torn away from the stays and blown against the opposite side of the box. In this engine, as in many other modern engines, the water had had to travel a distance of as much as 10 feet through the narrow and obstructed fire-box sides, from the boiler-barrel to the middle of the fire-box back. He would suggest that the supply of feed-water should be introduced at the middle of the fire-box back, and be directed sideways right and left, to travel round the sides of the fire-box and to maintain a continuous supply of solid water over the fire-box plates where they were most strongly heated. The object was not to effect a true circulation of the water in the boiler, as there would not be any return current, but to obtain a continuous supply of water to replace the water carried off by evaporation, and to supply this water at the point where it was most wanted. Mr. Marshall.

Mr. F. H. TREVITHICK remarked that the practice of the Egyptian State Railways had been, until recently, to use copper as the Mr. Trevithick.

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[Trevithick.

material for fire-box stays. Lately a trial had been made with bronze, in replacing broken stays, but sufficient experience of this metal had not been obtained to permit of an opinion being formed as to its utility compared with copper. The diameter of the stays when new was $\frac{7}{8}$ inch. From the time of his appointment as Chief of the Mechanical Department in 1883, a diagrammatic register of every boiler that had passed through the shops, in which were recorded the number and position of replaced stays and the date of every such renewal, had been kept by Mr. Otto, the foreman and boiler-inspector. The chief advantage of this system was that the life history of the boiler could be seen at a glance, and he recommended it to railway engineers. From such diagrams was derived the following information as to the results of the working of fire-box stays in sixty-four four-wheel-coupled passenger and eighty six-wheel-coupled goods engines.

No.	Maker.	Date of Construction.	Total Mileage to end of March, 1902.	Total Stays replaced.	Average Mileage per Stay replaced.
	Goods.				
20	Baldwin Locomotive Works, Philadelphia	1898	2,068,145	1[1]	2,068,145
10	Neilson, Reid & Co., Glasgow	1898	789,589	201	3,928
15	Société Franco-Belge, La Croyère, Belgium	1898	1,311,189	1,849	709
15	Société de Marcinelle et Couillet, Couillet, Belgium	1898–99	1,088,603	2,343	464
10	Société des Ateliers de Construction de la Meuse, Liège . .	1899	625,380	3,111	201
10	Société des Forges, Usines et Fonderies de Haine Saint-Pierre	1899	611,416	3,405	179
	Passenger.				
12	Neilson, Reid & Co., Glasgow	1889	4,185,842	2,831	1,482
52	Société Franco-Belge, La Croyère, Belgium	1890–95	14,074,623	4,592	3,065

[1] This solitary stay had to be replaced on account of defective thread in the plate, not for any defect in itself.

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The boiler-pressure in the instances selected, with the exception of the twenty Baldwin engines, was 140 lbs. per square inch. The Baldwin engines were worked at 160 lbs. per square inch. Of these engines, the sixty-four passenger and sixty of the goods engines were of English type and design, though constructed by different manufacturers (twenty-two being built by Neilson, Reid & Co., sixty-seven by the Franco-Belge Company and thirty-five by three other Belgian firms), the remaining twenty were American engines constructed by the Baldwin Company to their own design. The passenger engines, so far as the eye could judge, were identical in design. Fifteen goods engines were not only identical in design, but their boilers were also identical with those of the passenger engines, while forty-five goods engines were identical one with the other, and their boilers were also identical with those of the passenger and the fifteen goods engines, with the exception that the outside fire-box shell was raised above the boiler-barrel. The American boilers differed from the rest, especially as regarded the metal used, the plates and stays being made of mild steel in lieu of copper. The records bore out the Author's conclusion as to the position of the stays that were most liable to give trouble; but Mr. Trevithick's experience regarding the mode in which they gave trouble did not coincide with the Author's. Almost without exception on the Egyptian State Railways, stays had been replaced because they were completely, or in some degree, broken; no trouble had been experienced with leaky stays nor burnt heads, and the broken ends had invariably been the ends attached to the outside shell, not to the copper plate. The Nile water was excellent for boilers. The passenger engines and fifty of the goods engines had been stationed at the same depôt (Bulac, Cairo) and had been used respectively on similar work. Of the remaining goods engines, ten had been stabled at Gabbary, Alexandria, and twenty (Americans) at Tantah. As would be seen from the foregoing Table, the American engines had totalled 2,068,145 miles with one replaced stay, while the remaining goods engines had totalled 4,426,187 miles with 10,909 stays replaced, or one stay per 405 miles; the passenger engines had totalled 18,260,465 miles with 7,423 stays replaced, or one stay per 2,459 miles. A study of these records brought to light facts which merited the highest consideration, in order to find satisfactory reasons for results so widely different between the British and the American boiler, each typical in design and manufacture of the country of its origin. Very varied results in boilers constructed to the same drawings, conditions and inspection, but

Mr. Trevithick.

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Mr. Trevithick. by different manufacturers, had also been experienced. The excellent result of the Baldwin boiler must, he thought, be attributed to the fact that only one metal was used in constructing its various parts; the coefficient of expansion and contraction was thus the same in all parts, and the strain brought about by having different coefficients of expansion and contraction was obviated. Such remarkable results would, he thought, be a surprise to many, and would lead engineers to consider seriously the advisability of the use of one metal only in the construction of boilers. The cause of so varied a life of fire-box stays in boilers similar in design, construction and inspection, and which apparently had been worked and attended to under similar conditions, must, he thought, be sought for in the quality of the metal used. He could not account for it in any other way.

The Author. The AUTHOR, in reply to the Correspondence, stated that, with reference to Mr. Andrews's remarks on the enlargement of the crystalline structure of the copper-aluminium rolled rod (Figs. 25 and 26, Plate 5) when submitted to a temperature below redness for a short time, he had found that a similar result was obtained if the alloy were subjected to a temperature of 350° F. to 400° F. for a longer period. The crystal grains of the copper-aluminium stay (Fig. 12, Plate 4) used in the temperature experiments, after it had been in use 4½ months, had increased considerably in size, especially towards the furnace end of the stay. The good results obtained by the use of copper-manganese stays for high-pressure steam-boilers on the Northern Railway of France were certainly instructive, and worthy of the consideration of locomotive engineers. He understood, however, that the heads of the stays of this alloy did not wear so well as copper ones in the immediate vicinity of the fire, but in the upper part of the box, away from the fierce heat of the burning coals, they wore satisfactorily.[1] In regard to Mr. Drummond's experience of the temperature inside the fire-box, the Author had occasionally found the surface of the copper plates, in the vicinity of the brick arch, melted by the intense heat of the furnace, and the copper run down in the form of tears, when coal high in fixed carbon was used, indicating a temperature of fully 2,000° F. on the surface of the plates: and the actual temperature of the flame would be considerably higher. He had to thank Mr. Johnson for his valuable contribution to the discussion. The sample of pure copper tested by that gentleman was very similar in

[1] Le Blant, "Les Entretoises de Foyers de Locomotives." Congrès International des Méthodes d'Essai des Matériaux de Construction, Paris, 1900.

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composition to the special copper rod tested by him, and he thought Mr. Johnson also was giving it a practical trial. He anticipated that the result would be perfectly satisfactory. The copper-nickel alloy had not come under his notice, but the results of Mr. Johnson's mechanical tests of this material were very good, and it should, he thought, answer satisfactorily, provided a good joint and head were made. Although grooves undoubtedly added flexibility to a stay when it was clean, there existed a doubt in his mind as to whether the filling of the grooves with hard boiler scale would not considerably, if not entirely, reduce the flexibility gained by grooving. Consequently, he had never considered grooved stays worthy of a trial. The hardness of the copper alloys referred to by Mr. Jordan necessitated heavy blows being struck to form the head, consequently the threads were damaged or the holes distorted, as clearly shown in the riveting-tests. The analysis of the mild-steel stay and copper plate shown in Fig. 30, Plate 5, indicated that that stay was of the same composition as that given on p. 111. The copper plate had not been analyzed completely, but had been tested only for the hardening ingredient, arsenic, of which it contained 0·55 per cent. In fact, pieces from the same copper plate had been used in all the preliminary riveting-tests (Figs. 27–30). He might add that in all the riveting-tests (Figs. 27–37) hand-riveting had been resorted to, so that if there were any advantage in forming a joint by this method over that of pneumatic riveting, the specimens illustrated should show it. Mr. Marshall's suggestion for delivering the feed-water into the water-space of the fire-box had been tried years ago by the Author's predecessor, the late John Ramsbottom, M. Inst. C.E., on the locomotive "Lady of the Lake,"[1] which had been shown at the Exhibition of 1862. It had been found, however, that the introduction of the water, even warmed by the injector, into this part of the boiler caused the copper fire-box plates and stays to expand very unequally, giving rise to considerable trouble, and, in consequence, the practice had had to be abandoned. The correct place for delivery of the feed-water was certainly the barrel of the boiler, whereby the water was heated before reaching the intensely hot fire-box, and part of the mineral constituents were deposited where they would do least harm. The freedom from leaky stays and wasted stay-heads in the locomotive fire-boxes on the Egyptian State Rail-

The Author.

[1] Z. Colburn, "Locomotive Engineering and the Mechanism of Railways." London, 1876.

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Author. ways, mentioned by Mr. Trevithick, was undoubtedly due to the engines not having been heavily worked (although their mileage was fairly good) and at the same time to good boiler-water being universally available—a condition highly favourable to the life of steel boilers and fire-boxes. The freedom from breakage of mild-steel fire-box stays was well known, but, as already mentioned, the difficulty with them was the maintenance of a satisfactory joint when used in copper fire-boxes. Of course this defect would not be expected when they were used in steel fire-boxes, especially when good boiler-water was available. Boilers constructed entirely of one metal (mild steel) had, as at present designed, a much shorter life, and at the same time consumed a decidedly larger quantity of fuel as compared with boilers fitted with copper tubes and copper fire-boxes, and therefore could not, in his opinion, be considered altogether satisfactory.

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EXTRA MEETING.

23 April, 1902.

CHARLES HAWKSLEY, President, in the Chair.

THE "JAMES FORREST" LECTURE.

The PRESIDENT, in introducing the lecturer, remarked that Sir William Roberts-Austen, who had kindly undertaken to deliver the tenth "James Forrest" lecture, was so well known to engineers and metallurgists that very few words were needed to recommend the lecture to the earnest attention of the members. Sir William had come to the Institution notwithstanding the fact that he was still suffering from the effects of a serious illness; he therefore claimed indulgence should he not be able to make himself heard so well as he would wish.

"Metallurgy in its Relations to Engineering."

By Professor SIR WILLIAM ROBERTS-AUSTEN, K.C.B., D.C.L., F.R.S., Hon. M. Inst. C.E.

The Council has requested me to deal in this lecture with the relations which subsist between the metallurgist and the engineer; it must not, however, for a moment be imagined that the metallurgic art is not included in the wide range covered by the work of this Institution. It has from its earliest days earned the gratitude of members of my profession, and of miners as well as metallurgists, by discussing our Papers at its meetings, by publishing them in the Proceedings, and by placing us as Honorary Members in the roll of the Institution, which contains the names of so many distinguished engineers who have done so much for the country and the Empire.

"If I were called upon," wrote Mr. G. P. Bidder[1] in 1860, "to define the object and scope of the profession of Civil Engineer, I

[1] Presidential Address, Minutes of Proceedings Inst. C.E., vol. xix. p. 218.

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hould say that his particular province is to take up the results discovered by the abstract men of science, and to apply them practically for the commercial advantage of the world at large, and to diffuse their beneficent influences among all classes of his fellow-creatures." The metallurgist practising an industrial art has helped the engineer to do this, and in evidence I need quote no other testimony than that of Sir John Fowler, who wrote as follows in the Presidential Address he delivered in 1866:—"The profession has probably been assisted by the experiments and writings of its members and of distinguished men of science more in the material of iron than in any other substance." It is from iron and steel that my illustrations will be mainly borrowed.

It might at first be thought that the relations between metallurgists and engineers, which have become so intimate and enduring, arose quite simply from common interests. The metallurgist supplied materials which the engineer accepted for constructive purposes as being well suited to his needs, and co-operation might be supposed to have directly resulted from the recognition of the benefits that would arise from mutual service. The case is, however, far from being so simple as this. Communication between those who extracted metals from their ores and adapted them for the use of the engineer, and those who actually employed the metals in construction, has seldom at the outset been quite direct. Again and again in industrial history the relations we are to consider have been strangely stimulated by the intervention of men who sometimes were neither engineers nor metallurgists, but devoted their lives to abstract science. They recognised the value of certain metals and alloys for definite uses, they investigated their mechanical properties and proclaimed their merits to engineers. The intervener then disappeared, leaving behind some coefficient or constant bearing his name by which he became gratefully remembered. Such cases are frequently met with in the older history of metallurgy and engineering, and they constantly occur now. Two typical cases will suffice. One of these may well be taken from the Fifteenth Century, when the metallurgist did little for the engineer, and so much for the art workman. At a glorious period of Italian art and science, the astronomer, Galileo, brought metallurgists and engineers together. A visit to the Arsenal at Venice led him to study the mechanical properties of metals, and by applying the laws of mechanics to the endurance of solids, he incidentally showed what good service metals might render. We do not associate the great Florentine with a testing laboratory; he nevertheless stated that copper wires,

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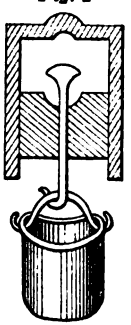
and consequently all cylinders of drawn copper, might be 4,801 brasses, or some 8,565 feet long, without breaking with their own weight.[1] The sketch (*Fig. 1*) shows the method he adopted for holding the test-piece, and has a singularly modern look.[2] The weights were placed in the receptacle.

It is a long step from the Fifteenth Century to the Nineteenth Century, but Dr. Thomas Young adopted a similar illustration when he wished to convince engineers that certain varieties of steel could be trusted for definite purposes. It was the rigidity of steel that Young wished to demonstrate; he therefore, between the years 1802 and 1807, gave us the very valuable constant that bears the name of "Young's Modulus." He pointed out that, if Hooke's law holds good, a hanging cylinder of steel would have to be 1,500 miles long in order that the upper portions of it might be stretched to twice their length, if that were possible without breaking the metal. It may be mentioned, parenthetically, that if such a cylinder 1,500 miles long were 1 foot $2\frac{4}{10}$ inches in diameter, it would represent a recent year's output of Bessemer steel in this country. It is the same story now; metallurgists who are working at the physical side of their art are presenting the engineer with metals and alloys which were undreamt of a century ago, and are inspiring confidence in their use.

Fig. 1



It is not easy to fix the period in industrial history when the metallurgist began to render the engineer essential service. Suppose that in this country Stonehenge were taken as a starting point. It is certain that metallurgists cannot claim to have been useful to the early civil engineer-architect who designed that crowning example of neolithic art. The venerable and stately structure arose from the plain at a time when bronze tools were known, but were not in general use, and had not replaced the stone axes and hammers by which the huge monoliths were dressed.[3] Mr. W. Gowland considers that the transition from the stone to the bronze age in this country may be placed at about 2,000 years before our era.

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[1] This calculation would not agree with tests of modern wire of pure copper; it more nearly corresponds with cylinders of hammered copper.

[2] "Évolution des méthodes et des appareils employés pour l'essai des matériaux de construction," communication par Mr. C. Fremont. Congrès International, Paris, 1900.

[3] *The Times*, 20 December, 1901.

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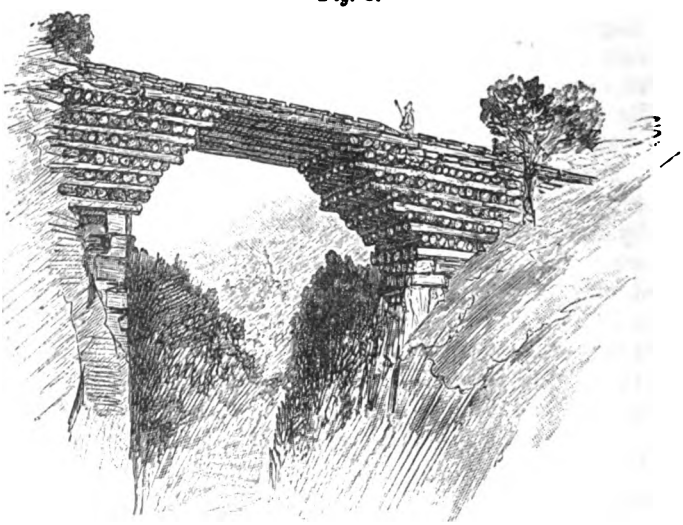
In another phase of engineering work, we know that Rome, in the days of her occupation of this country, looked to the metallurgists of our island to supply the lead of which the pipes were made that fed the aqueducts and baths of the eternal city.[1] The Romans also used metals in building construction, as is pointed out by Rondelet in his "L'art de bâtir" (Introduction, vol. i.), who gives as instances the portico of the Pantheon and the baths of Antonino Caracalla. Evidence, again, of the labours of the metallurgist is supplied by the well-known wrought-iron column at Delhi (Fig. 2, Plate 7), which has an inscription of the Fourth Century[2]; and again there are the Thirteenth Century iron girders and beams of the Orissa temples. Such magnificent efforts as these were not

Fig. 3.



maintained, and no widespread and continuous records of the metallurgists' contributions to early constructive work can be presented. On the other hand, the civil engineer advanced mechanical science and "directed the great sources of power in Nature for the use and convenience of man" for ages before the metallurgist rendered more than incidental assistance. The engineer availed himself of the wood and stone he found in a

[1] "The Early Metallurgy of Silver and Lead." W. Gowland, F.S.A., Society of Antiquaries, 1901, p. 18.

[2] "Some Evidence as to the very Early Use of Iron." Sir John Vincent Day, Phil. Society, Glasgow, 4 December, 1872.

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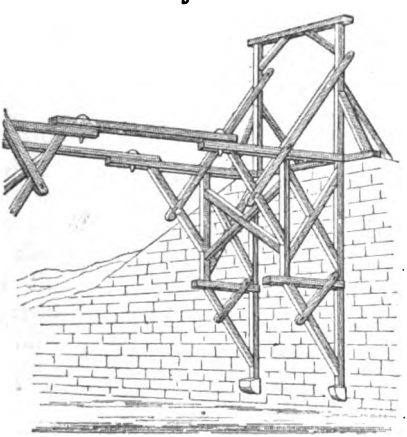
natural state, and the world has realised this, and has from very early days acknowledged a deep debt of gratitude for splendidly achieved aqueducts, bridges and embankments which were executed by members of the great profession it is now my privilege to address. Time will only permit me to offer a few illustrations. No metal finds a place in the primitive bridges which in the Middle Ages crossed deep gorges and mountain torrents in Savoy[1] (*Fig. 3*). Another instance is afforded by the very interesting Thirteenth Century cantilever bridge taken from the drawing of Villars de Honnecourt[2] (*Fig. 4*); it is made up of 20-foot wooden beams, which might have been much longer, and no metal enters into its construction. Or, to turn to the bascule bridge,[3] there were many examples so early as the Fourteenth Century of the type shown in *Fig. 5*, in which the only metal is the pivot A and the rod of the locking-lever B and the guide-rollers E E. As regards stone bridges, Ferrario describes the Ponte di Trezzo, which crossed the Adda in Northern Italy, and had a span of 237 feet and a rise of 68 feet. It was built by Bernabo Visconti about the year 1377, and was the largest stone arch known.[4] The great Tuscan painter, Leonardo da Vinci, 1452–1519, who said to have invented the pound lock and the breech-loading gun, had to trust to wood and stone for the erection of those wonderful structures which have rendered his name famous as an engineer. I give from his note-book a section of his design for the dome of Milan cathedral[5] (*Fig. 6*), with

Fig. 4.



[1] From a drawing by Mr. Charles Nicholson.

[2] "Album de Villars de Honnecourt, Manuscrit publié en fac-simile," J. B. Lassus et A. Darcel, 1858, Plate xxxviii.

[3] "Dictionnaire Raisonné de l'Architecture Français," par E. Viollet-le-Duc, vol. xvii. p. 255.

[4] Address by Sir B. Baker to Section G of the British Association. Report, 1885, p. 1188.

[5] "The Literary Works of Leonardo da Vinci," compiled from his original manuscripts by Dr. Jean Paul Richter. London, 1883.

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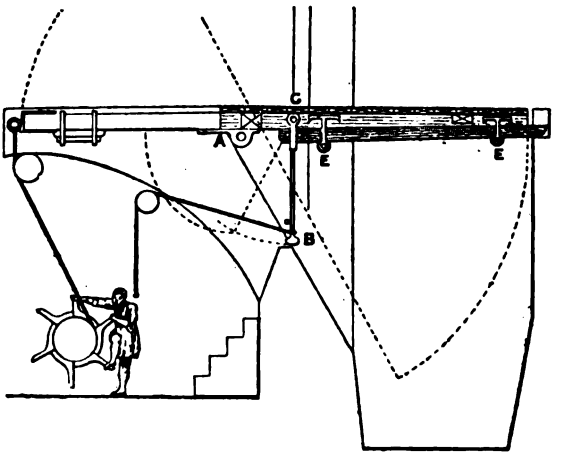
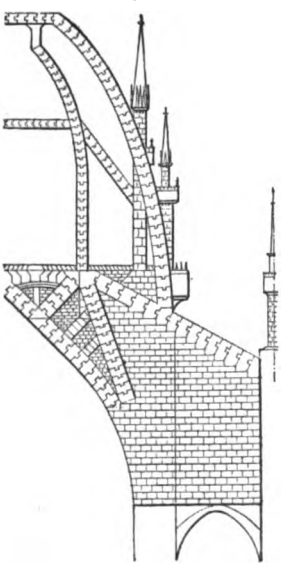
its interlocked stones. If we turn to Sixteenth Century work, the

Fig. 5.



Italian metallurgist, Vanoccio Biringuccio, or the German metallurgist, George Agricola, both wrote treatises, and the illustrations of the latter author show how small a part metals played in the engineering plant connected with the mining industry. In this way it would be possible to pass in review the intervening centuries to the sixteenth without there being much to record until the output of cast iron became considerable. The first cannon in this country were cast at Bucksted in Sussex in 1543, and it is well to remember that England owed much of her supremacy to the iron guns cast in the reign of Queen Elizabeth.

Fig. 6.



In Europe the metallurgist did not give the engineer much substantial aid until the Eighteenth Century. In that century works in cast iron were very noteworthy; but I can only cite a few of them, such as the Coalbrook Dale bridge, erected in the year 1777, with a clear

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span of 100 feet. As I shall have but little more to say about cast iron, it may be remembered that a plan was submitted to Parliament by Telford and Douglas[1] for crossing the Thames by a single arch of cast iron, of 600 feet span, but the experiment was considered to be too hazardous, and metallurgists lost this magnificent chance of rendering service to engineers. The Albion Mills, constructed by Rennie in 1784, and worked by Watt's steam-engines, are cited as the first example of the employment of iron in every part of machinery.[2]

In the Nineteenth Century, the metallurgist, as I hope to show, more than atoned for his somewhat tardy and intermittent efforts to supply materials for construction on an adequate scale. Viewing the century as a whole, it may be divided into three very unequal periods in relation to the production of iron and steel:—

I. For about two-thirds of the century cast iron and puddled iron were the main materials in use; then

II. The age of steel began and gradually gained vigour, while

III. Towards the end of the century great attention was devoted to considerations connected with the molecular structure and molecular properties of steel, and to enforcing the action of carbon by the addition of various other elements, often in very small proportions.

Henry Cort patented his great process of puddling in 1784, and as the Nineteenth Century dawned its merits were fully recognized. It is hardly possible to imagine that a metallurgical history of the world could provide a theme about which more eloquent pages could be written than those which describe the history of Cort's invention. The interest centres in the three great men—Cort, the inventor, Joseph Black, the chemist, and James Watt, the illustrious engineer. Cort's story has often been told, but I think that the relations between the three men I have named are neither sufficiently well known nor remembered. Our industrial supremacy as a nation was the outcome of those relations which, briefly stated, were as follows. Black discovered the latent heat of steam, Watt, by the improvement in the steam-engine, greatly facilitated the development of the blast furnace. It would be impossible to overrate the importance of this. It can be shown that the necessity for pumping water out of mines was the main factor in the evolution of the steam-engine; and, in turn, the development of

[1] An Encyclopædia of Civil Engineering, by E. Cresy, 1847, vol. i. p. 475.

[2] Presidential Address by Sir John Rennie; Minutes of Proceedings Inst. C.E., vol. v. p. 19.

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our national metallurgy of iron dates from the time when Watt's steam-engine enabled air to be readily pumped into the blast furnace. Cort, by the process of puddling, converted the product of the blast furnace into decarburized iron, which was in a sense a new material. It was the chemist Black who reported to the Government that the results of analyses, and of such mechanical tests as the period afforded, showed that puddled iron was more suitable than foreign iron, on which England had hitherto mainly depended for the manufacture of the appliance on which, as he said, the "lives of our seamen and the safety of our ships had depended." Let me quote the testimony of Fairbairn, who wrote as follows in 1865, at a time sufficiently remote from that at which Cort worked to enable his merits to be fully appreciated. He pointed out that this great metallurgist's inventions had "conferred an amount of wealth upon this country equivalent to six hundred millions sterling," and had during three or four generations "given employment to six hundred thousand of the working population of our land." It has been said that the history of many a great invention is one long martyrology. Cort's case is one of the saddest instances of this. His neglect by ironmasters and by the Government has recently been the subject of an eloquent appeal by Mr. Charles H. Morgan, who presided over the American Institution of Mechanical Engineers when this Institution offered its hospitality to American engineers in 1900. He said of Cort: "With one stride he stepped ahead of all competitors, scored a mark deep and lasting that will remain for ever upon the history of metallurgy and manufacture of iron as a magnificent landmark. It was his alone, and his reward has been practically nothing." I could only reply that Cort's name is emblazoned on the frieze of this room side by side with that of Watt and opposite the name of Newton, which bears eloquent testimony to the place he holds in the memory of engineers.

As regards the applications of wrought iron, I would only point out that the Nineteenth Century was but young when Robert Stephenson built his tubular bridge across the Menai Straits, which, as is well known, was 1,500 feet long, and one of its openings was no less than 460 feet. I must dwell no longer upon wrought iron, except to give the briefest reference to the ironwork of the great Exhibition of 1851, which gave us the "Exhibition girder," and to the "Great Eastern" steamship, an outcome of the genius of Brunel. As Sir John Wolfe Barry said in his Presidential Address, it is a lamentable thing that she should have been broken up for old iron. As the first half of the century was drawing to its close, I find that

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Sir W. Cubitt, F.R.S., in the Address he delivered as President of this Institution in 1850, refers to the Report of a Commission appointed in 1847 for the purpose of inquiring into the conditions to be observed by engineers in the application of iron in structures exposed to violent concussions and vibrations. The Report contains the following words, which suggest unbounded confidence as to the products then supplied by metallurgists and to the ability of engineers who used them: "Considering that the attention of engineers has been sufficiently awakened to the necessity of providing a superabundant strength in railway structures, and also considering the great importance of leaving the genius of scientific men unfettered . . . any legislative enactments with respect to the forms and proportions employed would be highly inexpedient." We shall see later of what vital importance, in relation to newer materials than wrought iron, the question of small but rapidly-intermittent stresses has become.

I must proceed directly to the second period into which, for the purpose of this lecture, the past century was divided. This begins with the year 1856, when the Bessemer process burst upon an astonished metallurgical world, to be followed later by the Siemens-Martin, or open-hearth process. It is unnecessary that I should describe these splendid metallurgical triumphs. As regards the first of these, Sir H. Bessemer presented a memorable Paper to this Institution in 1859. Steel produced by these two methods differed essentially in mechanical properties; but the important question is what reception could engineers accord to these new materials? They could only be expected to submit them to the methods of forging and annealing as they were then known, and judge them on their merits; and the results were in many cases very disappointing. The slowness with which confidence in steel was gained will appear remarkable, and the successive steps by which its reputation was established will be more rapidly gathered by a few quotations from Addresses of Past-Presidents of the Institution than from any other sources. Sir John Hawkshaw, in 1862, seven years after the date of Bessemer's patent, wrote as follows: "Should it turn out that steel, or homogeneous iron . . . uniform in quality, and of double the strength of ordinary iron, can be manufactured in large quantities at a moderate price, and can be easily manipulated; . . . then some things which cannot now be done at all, will be rendered practicable." Sir John Fowler, in 1866, takes a more hopeful view. He writes thus in his Presidential Address: "With respect to steel . . . before we can safely adopt it to any considerable extent for purposes

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of construction, it will be necessary to have careful experiments similar to those of Mr. Eaton Hodgkinson on the resistance and crushing force of cast- and wrought-iron; but," he adds, "so promising a material as steel will amply repay all the trouble that may be bestowed upon it." In 1877, Sir Nathaniel Barnaby had asked, as regards the use of steel for shipbuilding purposes, "What are our prospects of obtaining a material which we can use without such delicate manipulation and so much fear and trembling?" In 1877, Sir Frederick Bramwell,[1] not in his Address to this Institution, for that was not delivered until 1885, but in a lecture given elsewhere, predicted the great future that steel *properly treated* was destined to play. In 1880, Mr. W. H. Barlow, F.R.S., alludes to the fact that the Cunard "Servia" and the Allan "Parisian" were built of Siemens-Martin steel; and he points out that for great bridges "the employment of steel becomes a necessity, because the weight required to make them of iron would render them impossible." Lord Armstrong, in 1882, states, in reference to the inner tube of a gun, "I have always used steel for that purpose when I could obtain it of suitable quality, which, in the early days of my experience," he adds, "was a difficult thing to accomplish." By the year 1887, the address of Sir George Bruce shows that the merits of steel had at last received due recognition. The address is full of glowing statements, as well it might be, for the crowning triumph of the age of steel—the Forth bridge—had set the question of the case of steel at rest, and Sir George exultingly exclaimed, "At the Menai bridge the total quantity of iron was 11,468 tons; at the Forth bridge there will be 50,000 tons of iron and steel." Sir George concludes with the statement that in nothing is the effect of the use of steel more marked than in the railway interest throughout the world, for "steel rails, with a life far exceeding that of iron, are now produced at a price greatly below that at which iron rails were ever manufactured," and he points out that the use of mild steel for boilers had enabled a saving of 70 per cent. in the consumption of coal to be effected, and an increase of 110 per cent. in the speed of ships to be attained.

In 1895 Sir Benjamin Baker, in his Presidential Address[2] to this Institution, dwelt very fully on the apparently "mysterious" changes which take place when a steel rail cools down. In his Address, in 1885, as President of the Mechanical Section of the

[1] Proceedings of the Royal Institution, 1877, p. 314.
[2] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 1.

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British Association, he called attention to the extreme importance of rapidly-intermitted strains on steel. He showed that a very moderate stress, alternating from tension to compression, if repeated with sufficient frequency, say 100 million times, would cause fracture (in a shaft) as surely as sharp bending to an angle, perhaps only ten times. No one has done more than he to insist on the importance of phenomena which practical engineers are constantly encountering and cannot explain, and reluctantly have to relegate to the class known as "mysterious," but when the engineer has overcome these mysteries, and a Forth bridge, or some other great structure, is successfully erected, we are forbidden to consider it as a work of "transcendent genius," but as a symbol of the forces behind its designer, who is to be regarded merely as an exponent of the age of steel. While fully admitting the debt that genius owes to its environment, is there not danger in the view that leads us to undervalue the influence of personality? Personality is the channel through which the world receives any contribution to the advance of human progress, even though it be so great a one as to give an age its title—the age of steel. There are some men who, besides being the exponents of their age, belong to all time, and surely such men shed light from within, and do not merely reflect it from without. I like to remember that Browning makes the Chemist Paracelsus say that—

> "in man's self arise
> August anticipations, symbols, types
> Of a dim splendour ever on before
> In that eternal circle life pursues."

I must now come to the third period in the history of steel, which began towards the end of the past century—the period in which molecular structure and molecular properties of steel and other metals were studied.

The metallurgist must undoubtedly bear a large share of responsibility for the delay in recognising the most suitable methods of treating steel. It has been well said that "Where the physical explorer advances the engineer settler quickly follows."[1] The problems in the case of steel were, however, singularly complicated, and in the seventies the physical explorer had neither advanced far nor had obtained secure title to the territory. Now that the necessity of a National Physical Laboratory has been admitted in principle, and it has been proclaimed that the first work to be undertaken in it will be connected with steel and other alloys, the

[1] Sir B. Baker, Presidential Address Inst. C.E., *loc. cit.*

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nation should not, as new varieties of steel or new alloys are discovered, suffer the untold loss which delay in investigating the properties of ordinary carbon-steel has entailed.

What is it that metallurgists did when they gave the world mild steel? They provided iron containing, say, 0·2 per cent. of carbon, but that, on a small scale, had been known for centuries. They really gave a cinder-free solid solution of carbon in iron, a material the properties of which could be varied by the addition of other elements than carbon to the fluid bath and consequently to the solid solution which was produced by cooling the metal. Directly this was understood a field of wide extent was opened to the investigator. Let me, however, indicate the importance of such work by quoting the prophetic words of a Past-President of this Institution. Sir John Hawkshaw in 1862 wrote: "Men do not suddenly discover new worlds or invent new machines or find new metals . . . there is nothing worth having that has not been the result of 'combined and gradual' process of investigation. . . . Could we," he adds, "but hit upon an inexpensive mode of doubling the strength of iron, the advantages might be equal to those that would flow from the discovery of a new metal, more valuable than iron has hitherto been." The problem thus shadowed by Sir John Hawkshaw is being solved by metallurgists with regard to structural steel; they are "doubling" its strength by the aid of careful thermal treatment and by suitable additions of other elements than carbon. This result is not the outcome of random effort, but of patient investigation, the result of which has shown that steel is a solid solution of certain elements dissolved in iron. It is, moreover, a solid solution, the properties of which are profoundly modified by the presence of minute quantities of certain dissolved elements or substances, so that materials possessing a wonderful range of properties are presented to the engineer. I will try to set before you the nature of solid solutions as briefly as may be. Suppose any metal be taken, say lead. If it be melted it has, as is well known, a definite solidifying-point, or freezing-point, as it may be called, and this is known to be 326° C. Take another metal, say tin, which freezes at 231° C. The addition of either metal to the other will lower the freezing-point of the mixture (line A B C, *Fig. 7*). Any mixture of lead with tin will have two points of solidification, or rather two points which represent respectively the beginning and the end of the solidification of the mass. One definite mixture only of the two metals will have a single freezing-point; that is, the solidification of the mass begins and ends at one temperature. The

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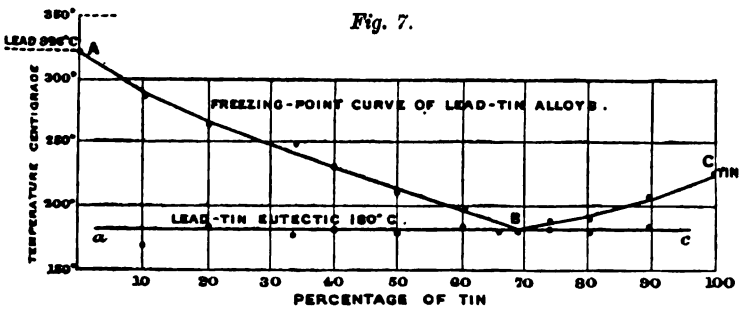
final freezing-point to which reference has just been made always occurs at the same temperature (*a c*, *Fig. 7*), and that temperature is the one at which the mixture of the two metals, which has only a single freezing-point, becomes solid. It is the same with the admixture of many salts, so that in a general way the freezing-point of mixed salts or of mixed metals is represented diagrammatically in *Fig. 7*. I might demonstrate this by noting the fall of a mercurial thermometer or of a pyrometer placed in a slowly cooling admixture of two salts or of two metals. But there is another way of showing it. I will freeze under the microscope a mixture of two substances, and for the moment it does not much matter what they are. Light passes through such a fluid bath of two substances and an image is projected on the screen. Presently it will be noted that the one substance crystallizes, freezes, and becomes apparently solid, but a portion has remained fluid, and in a moment or two it will also set, and crystals of it will project themselves through those first formed. These substances

Fig. 7.



are toluic acid and benzoic acid, and I owe the form of this beautiful experiment to Professor Laurie, Principal of the Heriot-Watt College, Edinburgh, who made the photographs, Figs. 8 and 9, Plate 8,[1] in my laboratory.[2] Now whatever mixture of two salts had been taken, the beginning of the freezing would occur at a variable temperature, but the end of the freezing always takes place at a definite temperature, coinciding with that of the eutectic mixture of the series.

The result would be exactly the same if I could render a bath of two metals transparent, or what is more important for the purposes of this address, if a fluid mixture of iron and carbon or of

[1] A description of the Figures in Plate 8 is given in the Appendix to the Lecture.

[2] The results of his beautiful experiments, in conjunction with Mr. Halford Strange, will, I trust, soon be published in full.

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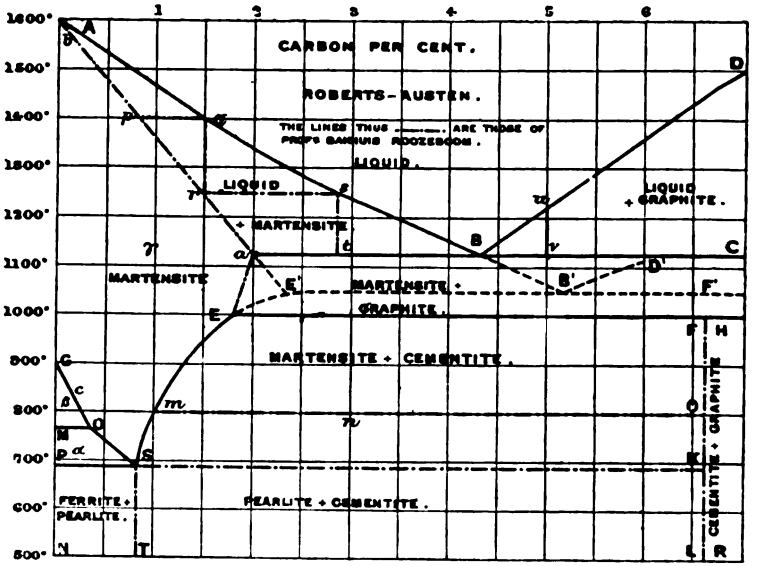
iron and carbide of iron could be made transparent, the result would closely resemble the freezing of the two salts. If, however, reference be made to the diagram (*Fig. 10*) which represents the solidification of carburized iron, a strange complication will be found to exist. All the points on this elaborate diagram have been fixed by noting the temperature at which there is an arrest of the spot of light from a galvanometer to which a thermo-junction is attached. This thermo-junction is placed in direct contact with the cooling mass of metal. It will be sufficient to state that all changes that take place in iron or steel below the line EF occur in solid metal. The

Fig. 10.



metal is solid, but it nevertheless possesses intense molecular vivacity. It will only be necessary to take quite a small portion of the diagram to make my evidence clear, and that portion is shown in *Fig. 11*. As the purest iron that has as yet been prepared cools down there is a sudden evolution of heat at 895° C. (the point marked G). There is another molecular change accompanied by an evolution of heat at 766° C. (the point M), and if carbon be present there is another change at 680° C. (point P). There are other changes[1] occurring respectively at 580° C., 487° C. and 261° C.,

[1] Fifth Report of the Alloys Research Committee, Proc. Inst. Mech. Eng., 1899, Plate 2.

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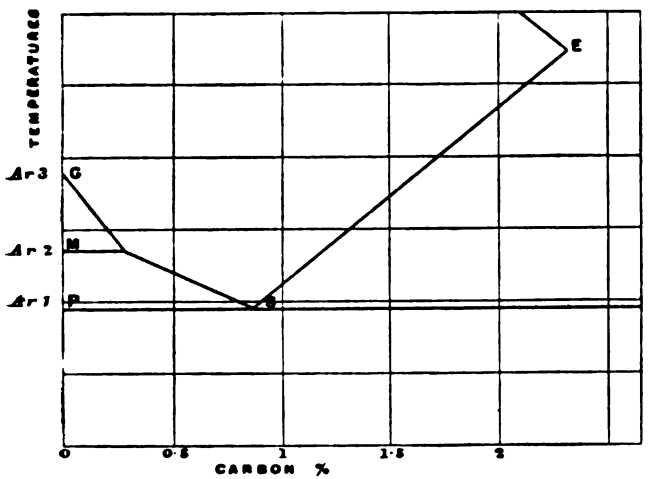
but their nature is at present very obscure. The presence of carbon or of certain other elements lowers the temperature at which these higher changes (895° C. and 766° C.) occur, and finally, when 0·9 per cent. of carbon is present, the three molecular changes are blended into a single one which assumes considerable proportions. I will attempt to show the change which occurs at 700° C., taking for this purpose a suitable variety of steel which contains some 0·8 per cent. of carbon. A spot of light from a galvanometer traverses the scale, a thermo-junction attached to the galvanometer is placed in a hole drilled in the steel, which is heated to some 1,000° C. When the temperature falls to 766° C. the metal will regain its power of

Fig. 11.



attracting a magnet, and you will see the spot of light borne by a magnetized needle move as the needle becomes attracted. Then at some 650° C. there will be an evolution of heat which will cause the upper spot of light to retrace its movement along the scale. Now this lower recalescence of steel is of great interest to engineers in connection with the hardening of steel, whether it be in the form of the smallest machine tool or the "A" tube of a gun. For this evening I would rather direct attention to the magnetic change and point to its importance. At 766° C. the iron undergoes an allotropic change; it passes from the β to the α state and regains its magnetism, but just as the freezing-point in a metal may be lowered by the presence of another metal, an allotropic or molecular change

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may also be lowered by the presence of certain other elements. The power which iron has of regaining its magnetic property at 766° C. is lowered by successive additions of nickel, and if iron be alloyed with 25 per cent. of nickel it is not only non-magnetic at the ordinary temperature but has actually to be placed in a freezing-mixture before it regains its magnetic property. This may be shown by an experiment similar to that by which the restoration of magnetic permeability to steel was demonstrated, the nickel-iron alloy being reduced to a temperature of about −50° C. by the aid of carbonic acid and ether. I have chosen this particular nickel-iron alloy on account of its interest and value to the engineer.

In 1899 Mr. Osmond of Paris communicated[1] to this Institution the results of some remarkable experiments of his own on the alloys of iron and nickel. In the case of an alloy containing 24·5 per cent. of nickel, the critical point, which occurs in ordinary iron at 766° C., is lowered to 40° C. and is not completed at the ordinary temperature. I have said that the alloy of iron with 25 per cent. of nickel is of great interest to engineers, and I will only add that Mr. Yarrow has pointed to its value in connection with the durability of water-tube boilers, and his conclusion[2] is as follows:—it is "not unreasonable to assume that nickel-steel (20 per cent. to 25 per cent. nickel) boiler-tubes will have, as regards acid corrosion, a vastly longer life than those of mild steel, and as regards deterioration from the action of heated gases or steam, at least twice the durability of mild steel." Surely this is very valuable evidence as to the importance of molecular variation. It would have been possible to demonstrate the same action in a simpler form. If steel containing some 1·5 per cent. of carbon be quenched in iced brine, it becomes comparatively feebly magnetic and has the structure shown in segment 4 of Fig. 12, Plate 8, and the substance produced has been called "austenite" by Mr. Osmond, who has shown that if this substance, austenite, be placed in liquid air and still further cooled it regains the power of magnetic permeability. In this case the quenching in iced brine preserved the β, or non-magnetic form of iron, to the ordinary temperature, and it required a further reduction of temperature by treatment with liquid air to produce ordinary or magnetic iron.

The question then arises, can we examine these mysterious actions at work and study their successive steps? First let me repeat that

[1] Minutes of Proceedings Inst. C.E., vol. cxxxviii. p. 312.
[2] Transactions, Institution of Naval Architects, vol. xli. p. 339.

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what has hitherto been considered a solid metal really behaves like a fluid. Our belief in the comparative solidity of lead was shaken when it was known that gold would diffuse itself into it with a considerable amount of freedom. Can we, from an examination of a solid metal, gain insight into its past molecular history? A page of Fénelon enables me to lead up to the means by which this may be effected. "There was no painter in the land of his imaginary travels, but the object to be copied was placed in front of water in basins, of gold or silver, and after a time the water froze and became a mirror on which an ineffaceable image remained." It is much the same with molten metals and alloys; when they become frozen or solid they retain in their mass, and often on their surfaces, impressions of the vibrations which have passed over them, and traces of their own internal molecular history which after suitable treatment the microscope will reveal. Three cases may be taken (Appendix and Figs. 12–14, Plate 8); in each set the magnification is the same,[1] and the material is of the same composition. Nothing is varied but the treatment to which the specimens have been subjected. The first (Fig. 12) is steel containing 1·5 per cent. of carbon; the second (Fig. 13) is iron containing 0·12 per cent. of carbon, and 2 per cent. of phosphorus; and the third (Fig. 14) is copper alloyed with 20 per cent. of tin. In the last two cases the changes have been entirely effected in the solid metal, as the treatment never involved melting the mass, and yet the changes have been profound and complicated. Many other illustrations of changes in the solid might have been given, but only two have been chosen, namely, Fig. 13, Plate 8, relating to iron to which phosphorus has been added, for which I am indebted to Mr. J. E. Stead, and Fig. 14, Plate 8, showing the changes produced by varying the thermal treatment of an alloy of copper and tin containing 80 per cent. of copper, which is the result of the work of Mr. W. Campbell, B.Sc., in my laboratory.[2] Even the ordinary testing-machine enables us to obtain an insight into molecular changes.[3] It has been shown that the stretched test-piece of steel becomes first cooler then warmer. The fall of temperature is proportional to the load up to a point below the elastic limit, and this point agrees closely with Wöhler's range for unlimited repetition of alternating stress.

[1] The centre of Fig. 13, Plate 8, and segment 6 of that figure are exceptions (Appendix, p. 171).

[2] Proceedings Institution of Mechanical Engineers, 1901, p. 1211.

[3] C. A. P. Turner on "Thermo-Electric Measurement of Stress." Transactions of the American Society of Civil Engineers, vol. xlviii. p. 140.

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Now as regards vibrations which permanently affect the structure of metals, the study of this very interesting subject is only just beginning, and I will only offer you a single case. Some years ago a young physicist, Mr. J. H. Vincent,[1] photographed, in the Royal College of Science laboratory, the waves into which the surface of mercury is thrown when it is set in vibration by a tuning-fork. The appearance of these waves will vary with the form of the walls of the vessel which reflects them. A circular receptacle presents the simplest case. They start from the vibrating point in circles and are reflected from the sides of the vessel (Fig. 15, Plate 8), but agitation produced by shaking the floor causes interference of these reflected waves and a rosette-like or cellular structure is presented (Fig. 16, Plate 8). But if a small quantity of pure lead or zinc be cast on glass the surface of the metal is found to be agitated by miniature whirlpools as in the case of the mercury.[2] First the reflection from a fluid bath of lead will be thrown on the screen; brilliantly coloured films of oxide soon cover the metal; yet thin as these films are they hinder the wave-like effect which was revealed on the surface of the clean mercury. Nevertheless, when the lead globule to which I have referred is cast on to glass and solidified, the microscope will show that the cell-like structure has been caught in the solid metal (Fig. 17, Plate 8). In case it should be thought that these are lines of a fusible eutectic in the mass, it must be remembered that the lead was pure, only traces of foreign metals being present. This experiment will, I trust, be sufficient to show that in the near future we shall know more about the vibrations that are so destructive to steel and other structures. Mr. Osmond is working at the subject, so we may hope for much. It may be thought strange that vibrations in a fluid should be retained in the solid, but of late years we have had to modify very materially our conception of solids; they behave, as we have seen, much like fluids. Nothing could show this better than the beautiful results obtained by Professor Ewing (himself a "James Forrest" lecturer), in conjunction with Mr. Rosenhain, on the growth of crystals in so-called solid metal.

There is one other great engineering work in which the efforts of the metallurgist have been very marked. I refer to the Alexander III. Bridge at Paris which crosses the Seine in a single

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[1] Phil. Mag., vol. 43, 1897, p. 411; vol. 45, 1898, p. 191; vol. 46, 1898, p. 290; vol. 48, 1899, p. 338.

[2] This subject is being studied by Mr. Osmond, who contributed a beautiful memoir on the subject to the Association pour l'essai des Matériaux. Congrès de Budapest, 1901.

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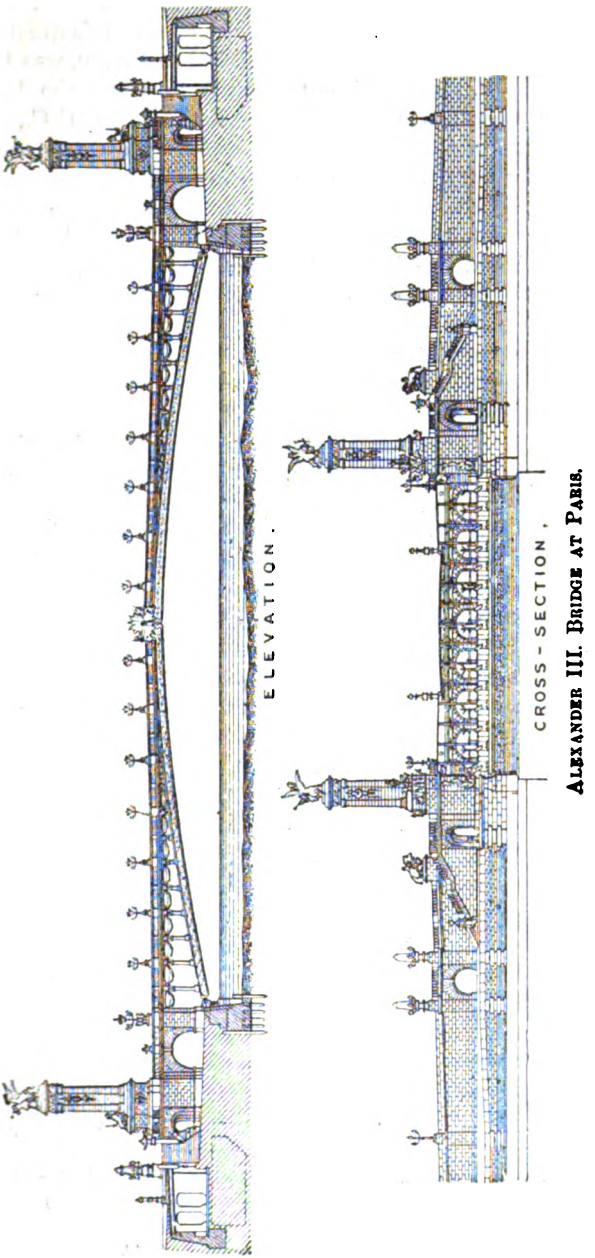

Figs. 18. ALEXANDER III. BRIDGE AT PARIS.

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span, and in the construction of which 2,200 tons of cast steel were employed, *Figs. 18*. The material used in this great work, by the distinguished engineers Messrs. Résal and Alby, was treated in a peculiar way. The different sections in which the bridge was cast were raised to a temperature of about 1,000° C., and then "quenched," as it were, by rapid cooling in air to about 600°, followed by very slow cooling to the ordinary temperature. It would lead me far beyond the limits of this lecture if I were to attempt to explain the molecular changes which take place in the solid metal and are involved in such treatment; but it may be added that the metal so treated becomes stronger and more elastic and resists shock better than if it had been annealed. This bridge, which, as so many of us felt, expressed the genius of the Exhibition of 1900, presents us with a remarkable instance of the importance of changes in the solid.[1]

To turn to another metal. Both metallurgists and engineers hope much for the action of nickel on steel, and I need only, in this connection, remind you of the remarkable process for the extraction of nickel from its ores which was submitted to you in the year 1898.[2] In this process of Dr. Mond, nickel is taken up from its ores by a gas, carbonic oxide, at a temperature of 50° to 100°, and released in the metallic form by subsequently raising the temperature of the gaseous nickel compound to 180° to 200°.

I am fully conscious how much more might have been said about the relations between the metallurgist and engineer had time permitted. I should like to have spoken of the hard, quick-cutting tool of the Bethlehem Works which astonished us so much in Paris during the Exhibition of 1900. Much might have been said as to the many uses which aluminium and its alloys are put to in engineering. We can readily imagine the use to which engineers will put aluminium in aerial navigation, from which so much is expected in the immediate future. Aluminium is rendering engineers service in the following unexpected way. A remarkable feature of modern metallurgy is the very useful action of small quantities of the rarer metals on the mechanical properties of large masses of steel. By enabling us to reduce such metals as nickel, cobalt and chromium from their oxides, aluminium is placing a supply of the rarer metals at our service. I have dealt with this subject fully and comparatively recently in a Friday evening

[1] "Notes sur la construction du Pont Alexandre III." By Messrs. Résal and Alby. Extrait des Annales des Ponts et Chaussées, 1898-1900. Dunod, Paris, 1900.

[2] Minutes of Proceedings Inst. C.E., vol. cxxxv. p. 29.

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lecture delivered at the Royal Institution "On Metals as Fuel."[1] It will only be necessary, therefore, for me to offer a few experiments which show the intense heat evolved when finely divided aluminium acts on metallic oxides and reduces them to metal, thereby playing the part hitherto allotted to such reducing agents as carbon or carbonic oxide. Three crucibles on the table contain respectively oxide of iron, oxide of chromium and oxide of cobalt, mixed in each case with a sufficient amount of finely divided aluminium to reduce the oxide. Combustion may be started by means of a strip of magnesium placed in a readily reducible oxide, such as oxide of barium, mixed with aluminium. Intense heat and dazzling light is evolved, the temperature reaching some 3,000° C., which is sufficient to melt the *alumina*, that is, the slag incidentally produced. The metal is melted and collects at the bottom of the crucible. The heat is, in fact, in excess of these requirements, and heat which would otherwise be wasted may be utilized for welding or other purposes.

I should have been glad, had time permitted, to deal with the improvements in the quality of copper used in electrical engineering. I will only say that if a metallurgist were now to offer the electrical engineer such copper as was supplied in the middle of the past century he would deserve to be relegated to the immortal pillory in which St. Paul placed Alexander the coppersmith who did him "much harm." I wish I could have told you how much metallurgists have aided military engineers in relation to ordnance. The question of the erosion of guns has assumed pressing importance, and I may remind you of a forgotten experiment of Count Rumford,[2] who, at the beginning of the past century, thought that the *erosion* must be due to the *corrosive* action of the products of the explosion of gunpowder in a closed chamber. He therefore employed a *gold* vent, and the fact that it became worn as a vent of hard steel had been, pointed to the rush of gas as the source of erosion, and not to corrosion by an acid product of combustion. The mention of military engineers reminds me of some observations in the Address of Mr. T. Hawksley (the father of the President), who pointed out in his Address delivered in 1872, that in no way other than by the study of ordnance and armour-plate would the Institution of Civil Engineers "serve its country better, or better

[1] *Nature*, vol. 64, p. 360. Proceedings of the Royal Institution, vol. xvi., part iii, 1902. See also a later Paper by Mr. Bertin in the Bulletin de la Société des Ingénieurs Civils de France, August, 1902.

[2] Philosophical Transactions of the Royal Society (abridged); 1796–1800 vol. xviii. p. 142.

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promote (in the interests of peace) the advancement of practical science and its application (if events should order) to the purposes of protective warfare."

In conclusion, I can only thank the Council for having permitted me to give one of the lectures by which this great Institution will always keep the memory of James Forrest in sylvan green.

The PRESIDENT, in proposing a vote of thanks to Sir William Roberts-Austen for his lecture, said the members had anticipated that vote by the hearty appreciation with which they had received the admirable discourse delivered by a distinguished Honorary Member of the Institution. They had not only listened with the greatest interest to the charming historical narrative with which Sir William Roberts-Austen had opened his lecture, but had also had the great advantage of witnessing beautiful and difficult experiments, experiments for the success of which they were indebted, not only to the lecturer, but also to the gentlemen who had assisted him. The Institution was under special obligation to Sir William because he had delivered his lecture at a time when, owing to recent illness, his task had been made much heavier.

Sir FREDERICK BRAMWELL, Bart., Vice-President, considered that the lecture had been most instructive to metallurgists and to engineers, and that it would be found of great service to the engineering profession. No one knew that service better than Sir Benjamin Baker and himself in their capacity as Members of the Ordnance Committee, for when there came before them a piece of steel misbehaving itself, which steel would sometimes do even nowadays, the Committee invoked the aid of Sir William Roberts-Austen. So far as it was possible to get into the middle of a piece of metal, Sir William Roberts-Austen had, he felt sure, been there, and knew what that middle was like; but ordinary men could not see into the middle of metal, in fact they could not see below the surface, and, therefore, many years ago, it had been thought that the best way of getting rid of as much unseen metal as possible, would be to have the minimum of solid metal combined with the maximum of surface; this was attained by using steel wire, or rather ribbon, instead of massive forgings. Moreover, not so many years ago, it had been by no means uncommon to find in the morning that a 10-ton piece of a gun, left in the turning-lathe over-night, had cracked spontaneously. Thanks to the instructions of science, this difficulty, as regarded large forgings for guns, had practically been surmounted. With regard to steel projectiles, however, intended to pierce armour, which day by day was being made more

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difficult to pierce, the nature of the steel, and the stresses set up in hardening, were such that it was by no means, even now, uncommon to have spontaneous rupture of such projectiles. Reverting to the steel ribbon, he was able to say that there had not been a single instance of an explosive burst where ribbon had been used. He did not think it was possible sufficiently to thank the lecturer for the great enlightenment he had given to engineers on the subject of that most important metal, steel, to say nothing of the enlightenment the members must have received from having been fortunate enough to witness the wonderful illustrations Sir William had shown them during the lecture. He felt it was a work of supererogation to urge upon the members to thank Sir William, as he was sure those thanks would be spontaneous.

The vote was carried by acclamation.

Sir WILLIAM ROBERTS-AUSTEN replied that he was exceedingly grateful for the thanks which had been given to him. It was easy to write a lecture, but it was not easy to carry through experiments of a difficult nature, and he was much indebted to his assistants who had so ably seconded him. He could not hope that any honour would arrive to him in his life greater than that of the Honorary Membership of the Institution. There was nothing he would not do to deserve the honour, and he was only too glad to be of the least use to the Institution. He was sure that even after a life-long friendship with Sir Frederick Bramwell, he could not have wished for higher praise than Sir Frederick had given him.

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APPENDIX.

Description of the Figures in Plate 8.

Fig. 8 represents the separation of benzoic acid crystals, from a mixture of benzoic and toluic acids, as projected on a screen, while Fig. 9 shows the final solidification of the mass, the eutectic of benzoic and toluic acids penetrating the spaces between the first-formed crystals revealed in Fig. 8. (Magnification in both cases 15 diameters.)

Fig. 12. "Cement steel" containing 1·5 per cent. of carbon. The magnification of each of the eight segments is 300 diameters, and the illumination vertical.

The circular disk in the centre of the series reveals the structure of the metal just as it comes from the cementation furnace. In segment No. 1 the steel has been heated to 1000° C., worked and slowly cooled. In it the carbide occurs in confluent masses, the groundwork being made of alternate bands of iron and carbide, so that the structure resembles mother of pearl, the association being called "pearlite." In segment No. 2 the same steel has been heated to 850°, and quickly cooled in air. The confluent masses have to some extent disappeared, and there is a groundwork of carbide in the distinct form to which the name "sorbite" has been given. In segment No. 3 the same steel has been heated to 850°, and quenched in water; it has thereby been "hardened," and the resulting structure is minutely acicular, the product being called "martensite." In segment No. 4 (the interest deepens) the same steel has been heated to 1050°, and quenched not in water but in iced brine. The result is totally different from "martensite"; there are broad chevron-like bands of "martensite" enclosing lighter and much softer portions, to which the name of "austenite" has been given by its distinguished discoverer Mr. Osmond; but a remarkable effect is produced when the same piece of steel shown in segment No. 4 is still further cooled by placing in liquid air, thereby cooling it to −243°. The material, as segment No. 5 shows, swells up and becomes "martensite," or something very like it, forming a fern-like structure of singular beauty. In segment No. 6 the treatment has resulted in partial reversion to the original structure, the metal having been quenched from a temperature near its melting-point, and what is known as a "burnt" steel is the product. Segment No. 7 shows the result of annealing the original steel at a temperature of 650° for a long time, followed by slow cooling; the result is well developed bands of cementite Fe_3C, and of the groundwork of pearlite. Finally, by heating any of the specimens except No. 6 to 850°, working them, and allowing them to cool slowly, the structure shown in segment No. 1 is practically again obtained, as shown by segment No. 8.

Fig. 13. The central photograph shows the appearance of a fractured surface of a sample of metal made by melting pure Swedish bar (Mark G. L.) with phosphorus. It contained about 2 per cent. of phosphorus and 0·12 per cent. of carbon. After melting, it was allowed to cool in the crucible in the fire. The rectangular cleavages are clearly visible. There is no magnification in this case, the structure shown being less than the natural size. Segment No. 1 is a

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portion of the same polished and etched with iodine. The light ground mass is phospho-ferrite, the dark envelopes pearlite, and the inclusions the eutectic of phosphorus and iron. Illumination, vertical. Magnification, 30 diameters. Segment No. 2 is another portion of the same metal after heating to about 1,200° C., and allowing to cool twenty-four times as slowly as was the case with No. 1. Etched with nitric acid in such a manner as to cause a darkening of the phospho-ferrite. The small area in the centre of the mass is the eutectic of phosphorus and iron surrounded by pearlite. Illumination, vertical. Magnification, 30 diameters. Segment No. 3 shows the same metal after prolonged heating with oxide of iron in order to effect an alteration of the condition of the carbon. The heating was conducted in a furnace of the type used in the production of malleable castings. The cooling from 1000° to 500° probably took about 24 hours. Pearlite is absent. The eutectic of phosphorus and iron, shown in No. 2 has been replaced by crystals of phosphide of iron. The specimen was etched with nitric acid. Illumination, vertical. Magnification, 30 diameters. Segment No. 4 is a portion of No. 3 after rapidly heating to 1000° C. It shows that the eutectic of phosphorus and iron has begun to form again and to diffuse into the surrounding iron. Etched with nitric acid. Illumination, vertical. Magnification, 30 diameters. The structure of the eutectic is too minute to be visible under such small magnification. Segment No. 5 is the same material as No. 3 after complete fusion in a magnesia crucible. Etched with iodine. Magnified 30 diameters under vertical illumination. The photograph shows a polished and etched cleavage face, and is one of the finest examples illustrating the varying degrees of diffusion in solid solutions. The dark skeletons running out at right angles to each other are spines of octahedral crystallites which separate from solution during solidification of the mass. It contains the lowest percentage of phosphorus and the highest of iron in the series. The first portions to separate out during solidification contain less phosphorus than those which separate later, the phosphorus in the solidifying portions gradually increasing while the temperature falls, until finally the eutectic alone remains. Segment No. 6 is a portion of No. 1, after being carburised in a cementation furnace. The narrow part represents the centre of the piece into which the carbon did not penetrate, and the broad end the part where the metal came into contact with the charcoal, and is consequently highest in carbon. The white-bordered elongated crystals are pearlite. The large white masses are phospho-carbide eutectic. Etched with iodine. Magnification, about 1·5 diameter. Segment No. 7 represents a solidified drop of liquated matter which adhered to the outer portion of No. 6. The structure was developed by oxidation or "heat-tinting." The lighter areas correspond to ferrite, the half-tones to phosphide of iron, and the dark parts to carbide of iron. Illumination, vertical. Magnification, 30 diameters. Segment No. 8 is another portion of the area of No. 7, showing in the centre the characteristic structure of the eutectic of phosphorus and iron, consisting of phospho-ferrite interlaminated with phosphide of iron.

Fig. 14. The copper-tin alloys containing 80 per cent. of copper. The magnification of all the segments is the same (15 diameters), and the illumination vertical.

The photograph in the centre of the circle is cast alloy annealed at about 750°. Segment No. 1 is alloy as cast. In segment No. 2 the alloy was quenched while liquid. Small angular grains of copper appear in a dark matrix, which appears to be structureless. Segment No. 3 is the same alloy quenched at a point below 870°, the cooling curve of the alloy indicating that a distinct molecular change

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takes place at that temperature. Segment No. 4 is the same alloy quenched at a temperature below 790°. In places the matrix is structureless, but generally it has the coarse-banded structure of a eutectic alloy. Segment No. 5 is the same as No. 4, but so etched as to enable the copper dendrites to appear under higher magnification. The characteristic structure of a eutectic is evident. In segment No. 6 the alloy had simply been cooled, while in segment No. 7 the alloy was cooled very slowly indeed. The dark dendritic crystals rich in copper increased in number and size, and the amount of eutectic has proportionately decreased. Segment No. 8 represents a portion of the alloy cut from near the surface of the solid mass. The experiments shown in Fig. 14 represent part of a series conducted in the Author's laboratory by Mr. W. Campbell, B.Sc., and published in the Proceedings of the Institution of Mechanical Engineers, 1901, p. 1211.

The object of the three sets of illustrations shown in Figs. 12, 13 and 14 is to indicate the complicated changes that may occur in *solid* alloys by variations in thermal treatment.

Fig. 15 is the projection of the ripples on the surface of mercury produced by a slender strip of metal (the dark radial line in the photograph) attached to a vibrating tuning-fork.

Fig. 16. Vibrations on the surface of mercury in a circular receptacle.

Fig. 17. Vibrations on the surface of a globule of lead, caught by rapidly cooling the globule on glass.

The preceding lectures of this series have been :—

Date.	Subject.	Author.	Proceedings Inst. C.E. Volume.
1893	"The Interdependence of Abstract Science and Engineering". .	Wm. Anderson, D.C.L., F.R.S.	cxiv.
1894	"Relation of Mathematics to Engineering"	John Hopkinson, D.Sc., F.R.S.	cxviii.
1895	"The Development of the Experimental Study of Heat-Engines"	Prof. W. C. Unwin, B.Sc., F.R.S. . .	cxxii.
1896	"Physical Experiment in Relation to Engineering".	Alex. B. W. Kennedy, LL.D., F.R.S. . .	cxxvi.
1897	"Bacteriology"	G. Sims Woodhead, M.D.	cxxx.
1898	"The Relation of Geology to Engineering"	Prof. W. Boyd Dawkins, M.A., F.R.S. .	cxxxiv.
1899	"Magnetism"	Prof. J. A. Ewing, M.A., B.Sc., F.R.S. .	cxxxviii.
1900	"The Relations between Electricity and Engineering"	Sir William H. Preece, K.C.B., F.R.S. . .	cxlii.
1901	"Chemistry in its Relations to Engineering"	Prof. Frank Clowes, D.Sc.	cxlvi.

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ANNUAL GENERAL MEETING.

29 April, 1902.

CHARLES HAWKSLEY, President, in the Chair.

The Notice convening the Meeting was taken as read, as well as the Minutes of the Annual General Meeting of the 30th April, 1901, which the President was authorized to sign.

The Report of the Council upon the Proceedings of the Institution during the Session 1901–1902 was read, the Statement of Accounts being taken as read.

After consideration, it was resolved,—That the Report of the Council be received and approved, and that it be printed in the Minutes of Proceedings.

The Scrutineers reported the election of the Council for 1902–1903 as follows :— [1]

President.

JOHN CLARKE HAWKSHAW, M.A.

Vice-Presidents.

Sir William Henry White, K.C.B., D.Sc., LL.D., F.R.S.
Francis William Webb.
Sir Guilford Lindsey Molesworth, K.C.I.E.
Sir Alexander Richardson Binnie.

Other Members of Council.

James Barton, B.A.
Horace Bell.
Benjamin Hall Blyth, M.A.
Cuthbert Arthur Brereton.
John Brown.
Robert Elliott Cooper.
Rookes Evelyn Bell Crompton, C.B.
Cecil West Darley.
George Frederick Deacon.
William Robert Galbraith.
Edmund Phillips Hannaford.
George Henry Hill.
James Charles Inglis.
George Robert Jebb.
Alexander Blackie William Kennedy, LL.D., F.R.S.
Sir William Thomas Lewis, Bart.
John Allen McDonald.
William Matthews, C.M.G.
William Shelford, C.M.G.
Alexander Siemens.
Henry Charles Stanley.
John Strain.
John Isaac Thornycroft, LL.D., F.R.S.
William Cawthorne Unwin, B.Sc., F.R.S.
Frederick Robert Upcott, C.S.I.
Sir Edward Leader Williams.

[1] The Council commence their year of office on the first Tuesday in November, 1902.

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Resolved,—That the thanks of the Meeting be given to the Scrutineers, and that the Ballot-Papers be destroyed.

Mr. John J. Webster responded on behalf of the Scrutineers.

Resolved,—That the thanks of the Institution be tendered to Messrs. John George Griffiths and Alexander Ross, for the time and trouble bestowed by them in auditing the Accounts for the past financial year; and that Messrs. Percival Davis Griffiths, A.C.A., and Walter Hunter be appointed Auditors for the current financial year.

Messrs. Griffiths and Ross acknowledged the Resolution.

Resolved,—That the thanks of this Meeting be accorded to Mr. Charles Hawksley, President, for his conduct of the business as Chairman of the Meeting.

The President acknowledged the Resolution.

The proceedings then ended.

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REPORT OF THE COUNCIL, 1901–1902.

In presenting this Annual Report, the Council have to direct the attention of the members to several important undertakings which have been entered upon, or have been concluded, during the past year.

First may be mentioned the inquiry, upon which the Council embarked a year ago, into the desirability of standardizing ordinary practice in respect of some of the materials of construction in daily use by engineers. The Committee charged by the Council to investigate this matter, with the ready co-operation and aid of the Institutions of Mechanical Engineers and of Naval Architects, as well as of the Iron and Steel Institute, has already reduced many of the difficulties which appeared to beset any general scheme for the establishment of engineering standards in this country; and the original reference has been enlarged to embrace the question of the standardization of locomotives, and of tests for materials. Whilst the Committee is not yet in a position to report fully on the several branches into which its inquiry has developed, its work in some of them is well advanced, and the Council have reason to expect at an early date the presentation of results arrived at in certain important parts of the investigation.

A work of great value, which the Council are now enabled to place at the disposal of the Institution, is the Report of the Committee appointed to propose a uniform system of tabulating the results of steam-engine and boiler trials. The labours of this Committee, begun in 1897, have been protracted owing to various causes—not the least of them being the time necessarily occupied by testing, under the conditions of actual practice, the rules proposed for general guidance in such work, and the Forms to be employed in recording the results obtained therein. The extensive nature of the investigation is testified by the Report itself, which, although carefully edited and condensed, occupies twenty-four folio-sheets of closely printed matter, and eleven tabular Forms. To Captain H. Riall Sankey, M. Inst. C.E., the Chairman, to Prof. Hudson Beare, M. Inst. C.E., the Honorary Secretary, and to all the members of the Committee, the Institution owes a debt of extreme gratitude for their labours. The members generally will also share with the Council the deep regret they feel that

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Mr. Bryan Donkin has not lived to witness the consummation of the work, in which, as a member of the Committee, he took so keen an interest, and the inception of which was largely due to him.

The success of the International Engineering Congress which was held at Glasgow in September, 1901, justified the anticipations of the Council expressed in the last Annual Report. The gathering, under the Presidency of Mr. James Mansergh, then President of this Institution, was well attended, some 520 members of the Institution taking part in it, in addition to those attached exclusively to other societies, and to the foreign delegates. The overlapping of the membership of engineering societies in Great Britain, although not numerically so extensive as is frequently supposed, constitutes some drawback if debates are conducted simultaneously by bodies dealing with particular branches of engineering. Somewhat of this disadvantage was experienced at the Congress, which nevertheless did valuable work, and undoubtedly promoted that co-ordination of the various departments of engineering, which it has always been the object of this Institution to foster and to maintain. It had been felt that the Congress, to the success of which a good deal of effort was directed by individual members of the Institution, should take the place of the Engineering Conference in London which would in the ordinary course have been held last summer. It is hoped to repeat the Conference next year on the same lines as formerly.

As the result of renewed consideration of the question in regard to the metal of which the Telford, Watt, and George Stephenson Medals should be made the Council have this Session come to a decision that these medals should in future be of solid gold, and be thus henceforth of the intrinsic value they apparently represent. This change can be effected without any alteration being made in the total values of the awards as given on the lines observed previously; the only difference being that the value of the premiums of books hitherto accompanying the gilt medals will be merged into the value of the medals themselves, the award of which will thereby become at the same time a more distinctive mark of merit than heretofore.

The examinations held by the Institution continue to give satisfactory results, and the numerous applications for entrance to them indicate that in scope and standard they are generally suitable to the present conditions of engineering training in its various branches. The Council have pleasure in announcing that the late Mr. John Bayliss, Assoc. Inst. C.E., has bequeathed £1,000 for the establishment of "Bayliss" prizes, which will be

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awarded annually to the Candidates who, being present or former Students of the Institution, may obtain the highest marks in the Associate-Membership Examinations held in the preceding October and February. The prizes are awarded this year to Mr. James Lowe and Mr. I. V. Robinson, Studs. Inst. C.E., in respect of the last October and February examinations, in which examinations Messrs. A. F. Wedgwood and J. G. Mathieson, Studs. Inst. C.E., also especially distinguished themselves.

The Roll.

The changes which have taken place in the Roll during the year ending the 31st March, 1902, are shown in the accompanying Table. The elections comprised 1 Honorary Member, 28 Members, 157 Associate Members and 11 Associates; while the names of

	April 1, 1900, to March 31, 1901.					April 1, 1901, to March 31, 1902.				
	Honorary Members.	Members.	Associate Members.	Associates.	Totals.	Honorary Members.	Members.	Associate Members.	Associates.	Totals.
Numbers at commencement	19	2,033	3,989	311	6,352	19	2,067	3,990	300	6,376
Transferred to Members	..	73	73	..		..	69	69	..	
Elections	3	25	166	5	206	1	28	157	11	207
Restored to Register	..	2	5	..		..	1	9	..	
Deaths	2	47	40	7	182	..	40	39	9	156
Resignations	1	12	25	9		..	14	17	3	
Erased	..	7	32	..	24	..	..	33	1	51
Numbers at termination	19	2,067	3,990	300	6,376	20	2,111	3,998	298	6,427

1 Member and 9 Associate Members were restored to the register. Against this total addition of 207 must be placed 156 names which, owing to death, resignation and erasure, have disappeared from the list, leaving an effective increase of 51.

The number on the Roll, exclusive of Students, on the 31st March, 1902, was 6,427, that on the corresponding date of last year having been 6,376.

It is found that about two-thirds of those who are elected Associate Members are examined by the Institution, the remaining third being qualified by exempting degrees. In the admission of Students the converse of this condition obtains.

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The full list of deceases is as follows:—

Members.—Richard Dansey Bayley; Frederick Beesley; George Arthur Biddell; William George Brounger; Philip Henry Brown; Richard Henry Brunton; Henry Richard Carleton, M.A.I. (*Dubl.*); Henry Robert Pasley Carter; Thomas Chapman; Thomas Curtis Clarke; William Wikeley Clayton; William Santo Crimp; Bryan Donkin; Patrick Duncan; George Farren; Willoughby Charles Furnivall; Walter Thomas Goolden, M.A. (*Oxon.*); John Hopkinson; John Barker Huntington; Walter Robert Kinipple; Hugh Leonard; Walter Merivale; Charles Yelverton O'Connor, C.M.G.; Edward Emmerson Oliver; George Owen; Henry Sadleir Ridings, M.E. (*Queen's*); William Robert Robinson; Thomas Rumball; James Carrington Simpson; William Starling; Hyalmar Frederick Stavelius; Francis Stevenson; Joseph Thomas; William Henry Thomas; George Frederick Tippett; James Penman Hugh Walker; Robert Attwooll Way; Alfred Williams; Charles Wood; and George Scholey Young.

Associate Members.—Clemens Xaver Julius Allmann; Frank James Appleby; Arthur Howard Benham; Arthur Crompton Brown; Alfred Benigno Alexander Chester; William Colson; John Cooper; John Drake; Daniel Earnshaw; Henry John Eunson; Frederick Flood, M.A. (*Cantab.*); William Fraser; Matthew Gray; Alberto Joseph Pimentel Hargreaves; William Samuel Jones; Henry Harington Leigh; Joseph Leslie; Joseph Slater Lewis; Alfred James Linnell; Peter Arthur Mackintosh; Thomas Thomas Marks; Arthur Marshall, B.A. (*Cantab.*); Frank Edward Berra Nathan; Frank Owen; John Paterson; Alfred Pearson; James Ponsfold; Charles Steuart Bell Sanderson; Christopher Robert Ind Scott; George Samuel Searight, B.A.I. (*Dubl.*); Robert Holroyd Slade; *Khan Bahadur* Bomanji Sorabji; Charles Edward Stewart; Rennie Charles Augustus Twyford; Joseph John Tylor; Frank Adamson West; Charles Louis Napoleon Wilson; Gerald Merrett Wynter; and Robert George Young.

Associates.—James Clark Bunten; *Sir* James Timmins Chance, *Bart.*, M.A. (*Cantab.*); John Corbett; Walter Marden Ducat, *Colonel* R.E. *retired*; *Sir* Thomas Lucas, *Bart.*; George Edward Langham Somerset Sanford, *Lieutenant-General* R.E., C.B., C.S.I.; Henry Minchin Simons; Matthias Erasmus Wesley; and Charles Stroud Williams.

The following resignations have been accepted:—

Members.—William Lind Buyers; Bernard William Cantopher; William Douglass; Robert Gordon; Cecil William Edward Henslowe; William Francis Jackson; Henry Johnson; John Charles Johnston; John Kershaw; Robert Aspland Marillier; Benjamin Martell; William Stevens; Robert Allen William Swinnerton; and Wesley William Wilson.

Associate Members.—Thomas Alexander Allan; Miles Aspinall; Henry Blackbourn; John Edward Augustus Jenkins Blandy; James Edward Neville Boydell; Henry John Bridgewater; Edward Clarke; Charles John Geneste; Franklin Hilton; Ernest Lupton; John Smith McNeill; Domingo Merry del Val y Zulueta; Frederick Thomas Reade; Robert Stoney Sheffield; James Nasmyth Sidebotham; George Herbert Wailes; and Alexander Wilson (of Melbourne).

Associates.—Isaac Adolphus Crookenden; William Henry Hodges; and the *Right Hon.* Andrew Graham Murray, K.C., M.P.

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Students.

The Table hereunder shows the changes which have taken place in the Student class during the year ending the 31st March, 1902. The admissions numbered 209, or 24 more than last year, while 221 names were removed from the list. Of these 53 and 1 were elected to the Associate Member and Associate classes respectively, and 135 retired on attaining the age-limit of the Student class. It is satisfactory to find that of the 157 candidates elected to the Associate Member class during the period under consideration, 96, or nearly two-thirds, were, or had been formerly, Students. The total number of Students on the 31st March was 959.

Students.

1900–1901.			1901–1902.		
April 1, 1900		1007	April 1, 1901		971
Admitted during the year	185		Admitted during the year	209	
Elected Associate Members	41		Elected Associate Members	53	
Deceased	2		Elected Associate	1	
Resigned	27		Deceased	4	
Erased	22		Resigned	16	
Removed—over age	129		Erased	12	
	221		Removed—over age	135	
	36			221	
				12	
March 31, 1901		971	March 31, 1902		959

Finance.

The Statement of Accounts for the year ending the 31st March, 1902, duly audited, will be found at p. 184.

The receipts on Income account amounted to £23,314 6*s.* 8*d.*, as against £23,036 3*s.* 2*d.* last year; on Capital account (admission fees and life compositions) £2,134 13*s.* 0*d.*; and from Trust Funds, including a bequest of £1,000 from the late Mr. John Bayliss, Assoc. Inst. C.E., £1,480 18*s.* 2*d.*: making a total of £26,929 17*s.* 10*d.* The receipts on Income account included subscriptions £19,161 4*s.* 0*d.*, dividends £1,853 19*s.* 6*d.*, rents £1,061 12*s.* 1*d.*, and examination fees £500 6*s.* 6*d.*

The expenditure on Income account, amounting to £22,070 5*s.* 6*d.* against £21,459 15*s.* 11*d.* last year, included contributions of £250 4*s.* 6*d.* and £504 19*s.* 6*d.* respectively to the expenses of the Committee on Standard Sections and the International Engineering Congress held at Glasgow in September, 1901, and examination expenses, £513 15*s.* 2*d.*

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On Capital account the sum of £2,840 13*s.* 6*d.* was invested in Consols, and on Trust Funds account the expenditure was £1,427 8*s.* 4*d.*, including the purchase of £1,013 17*s.* 10*d.* London County 3 per cent. Consolidated Stock to represent the Bayliss Bequest above referred to, and £10 6*s.* 2*d.* Metropolitan 3 per cent. Stock purchased with unexpended dividend on Palmer Scholarship account.

The investments on Institution account amount to £64,600 (nominal value), purchased for £65,810 1*s.* 2*d.*, and on Trust Funds account to £18,168 4*s.* 9*d.* (nominal value).

Sessions and Meetings.

During the past Session twenty-one ordinary meetings have been held, at which eleven Papers were read and discussed, the first meeting in November being, as usual, devoted to the delivery of an Address by the President, and to the presentation of medals and premiums. The attendances have on the whole equalled an average of those of recent years; a few evenings that were deficient in this respect, owing to the very foggy weather experienced during the winter, being compensated for by the large numbers which were present on several other occasions. It has long been recognised that the attendances at the meetings have not increased *pari passu* with the growth of the Institution. The wider distribution of the members, the calls on many of them to take part in other proceedings of especial interest to particular branches of the profession, and the better facilities afforded to those who would otherwise speak to send in their contributions in writing, all, doubtless, conspire to limit the attendance on Tuesday evenings. Having regard to the very full character of the recent discussions, the Council have scarcely reason to exhort the members upon the subject of active interest in the proceedings of the Session; but they may perhaps, remind them of their promise to attend the meetings of the Society as often as they conveniently can do so.

The subjects considered during the session were of a fairly representative character. Railways—or rather, the problems presented in certain departments of their working—were dealt with by the communications of Mr. J. A. F. Aspinall on "Train-Resistance," of Messrs. Mordey and Jenkin on "Electrical Traction on Railways," and of our Vice-President Mr. Webb on "Locomotive Fire-box Stays." Of these communications, that on Electrical Traction elicited a discussion extending over five evenings, being with two exceptions the longest that has ever taken place at the

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Institution.[1] Allied to the last-named Papers, although mainly from a constructive point of view, were the two contributions on tunnelling by Mr. W. C. Copperthwaite and Mr. Arthur Haigh, respectively entitled "The Greenwich Footway Tunnel" and "Subaqueous Tunnelling through the Thames Gravel; Baker Street and Waterloo Railway," devoted chiefly to describing the method of shield-working under conditions of hydrostatic pressure. Thus, exactly one-half of the meetings of the Session were devoted to the consideration of subjects connected with means of communication, which has always held a most important place among the many interests to the promotion of which the engineer's art is directed. Of the other topics dealt with, sewerage and the disposal of sewage or waste products claimed three examples in the Papers of Mr. Kaye Parry and Dr. Adeney on "The Discharge of Sewage into a Tidal Estuary;" "The Sewerage Systems of Sydney, N.S.W., and its Suburbs," by Mr. Joseph Davis; and "The Bacterial Treatment of Trades Waste," by Mr. W. Naylor. These Papers and the discussions evoked by them, will, it may be hoped, afford to sanitary engineers some guidance in coping with one of the most difficult problems presented by modern civilization, namely, the avoidance of the pollution of rivers and other waterways. The communication on "The Port of Dundee" by Mr. G. C. Buchanan, formed a sequel to the account of the Tay estuary and its engineering works presented by another member some years previously; and afforded a comparison of a seaport equipped with the contrivances of modern practice with its forerunner of seventy years ago on the same site. Mr. Bryan Donkin's Paper on "Motive-Power from Blast-Furnace Gases" indicated the latest developments in the efforts to render available a source of power which until recently was very imperfectly utilized in this country. Mr. Molesworth's valuable contribution on "American Workshop Methods in Steel Construction," read a few weeks later, served further to direct attention to the question of an alleged want of enterprise or of method among British engineers; and the discussion which took place upon it will no doubt serve to explain some points in relation to foreign engineering competition which were previously obscure.

For Papers read and discussed at the meetings the Council have had pleasure in making awards to Messrs. W. M. Mordey; B. M. Jenkin; J. A. F. Aspinall; W. C. Copperthwaite; A. H. Haigh;

[1] The discussion on Mr. G. P. Bidder, jun.'s Paper on the National Defences occupied six evenings in 1863; that on the metre gauge for Indian Railways, by Mr. W. T. Thornton, five evenings in 1873.

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and J. Davis. They desire to record their high appreciation of Mr. Bryan Donkin's Paper, above mentioned; and to express their best thanks to Mr. Webb, Vice-President, for the valuable account of his experience with "Locomotive Fire-box Stays."

The Howard Quinquennial prize is awarded this year to Mr. R. A. Hadfield, M. Inst. C.E., for his scientific work in investigating methods of treatment and new Alloys of Steel, and on account of the importance in industry of some of the new products introduced by him.

The Papers selected for publication in the Proceedings without being discussed will be found to cover as varied a field of research and description as those published in former Sessions. The awards for these Papers will be determined on by the Council during the recess, and will be announced in the usual course in the autumn.

The formal presentation of medals and premiums will take place at the opening meeting of next Session.

Students' Meetings and Visits to Works.

During the Session nine Students' meetings have been held in London. At that on the 17th January Captain H. Riall Sankey, R.E., M. Inst. C.E., delivered a valuable address on "The Theory of Heat-Engines," a copy of which has been furnished to every Student on the list; and at the remaining meetings eight Students' Papers have been read and discussed. Including the work of the Associations of Students in the country twenty-two Papers have been read by Students during the Session, ten of which are submitted in competition for the Miller prizes. The customary visits have been made to engineering works.

The following Table shows the average attendance of Students at meetings and visits to works, and the average number of speakers in the discussions at meetings in London, for the past three Sessions.

Session.	1899–1900	1900–1901	1901–1902
Attendance at meetings	40·5	36	34
„ „ visits	25	20·5	20·5
Speakers at meetings	4·2	4·6	6·7

On the 8th May, at the invitation of the President, and by the kind permission of the Directors of the Bristol Waterworks Company, the Students are to inspect the new Yeo Reservoir and Pumping Station of the Bristol Waterworks. Arrangements have been made for Woolwich Arsenal to be visited on the following day.

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The "James Forrest" Lecture.

The tenth "James Forrest" lecture was delivered on the 23rd April by Sir W. C. Roberts-Austen, K.C.B., Hon. M. Inst. C.E., the subject being "Metallurgy in its Relations to Engineering." The Council have to record their gratitude to the lecturer for his most interesting discourse upon that subject, as well as for his kindness in repeating the lecture on the afternoon of the 25th April.

Library Catalogue.

The Subject Catalogue of the Library corresponding with the Author Catalogue of 1895 has been completed and in use for some months past. Its compiler, Mr. H. B. Wheatley, is still occupied with some revision of the text, and on the conclusion of this work it is proposed to print a number of copies. Members who may desire to possess the complete Subject and Author catalogues may then acquire them on payment of the printing and binding charges.

The Premises.

As may be seen in the Statement of Accounts, a considerable sum of money has been expended upon the property of the Institution during the past year. The repairs to No. 27, Great George Street, were necessary to maintain the house in such good condition as to avoid all cause of complaint on the part of the freeholders of that property, and to meet the reasonable requirements of the tenants. The expenditure on the freehold premises of the Institution has been principally incurred in connection with the doorways formed to afford access to No. 27, to facilitate the more effective use of that house as occasion requires.

As an indication of the extent to which use is made of the accommodation which the Institution is able to afford—sometimes it may be with slight inconvenience to members owing to limited space—it may be mentioned here that 103 Ordinary, Council, and Committee meetings on Institution business proper, and 40 meetings of other bodies, have been held in the rooms during the past six months.

The collection of portraits has been enriched by gifts of those of Mr. James Mansergh, F.R.S., Past-President, painted by W. M. Palin; and of Sir Frederick Abel, Bart., Honorary Member, painted by Frank Bramley, A.R.A. The Council have also received from Mr. F. Douglas Fox a marble bust of the late Sir Charles Fox, a distinguished and honoured member of the Institution.

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ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.

	£. s. d.	£. s. d.
To Balance, 1 April, 1901, viz. :—		
On Deposit	5,500 0 0	
Cash in the hands of the Treasurer . . .	957 12 11	
„ „ „ Secretary . . .	17 4 8	
		6,474 17 7
Income.		
— Subscriptions received :— £. s. d.		
Arrears, prior to 1 January, 1901 453 1 6		
For the year 1901 . . . . 4,924 5 6		
For the year 1902 . . . . 13,763 18 0		
Advance 19 19 0		
	19,161 4 0	
— Minutes of Proceedings :—Repayment for Binding, &c.	516 19 6	
— Library Fund	97 19 6	
— Dividends : 1 year on		
£ *Institution Dividends.*		
2,000 2½% Consols . . .	51 18 3	
4,000 Manchester Corporation 3% Stock	113 0 0	
4,000 London County 3% Stock	113 0 0	
6,000 Metropolitan 3½% Stock	198 3 9	
6,000 Great Eastern Railway 4% Debenture Stock.	226 10 0	
8,000 Great Northern Ry. 3% Debenture Stock . .	226 10 0	
8,000 Great Western Ry. 4% Debenture Stock . .	302 0 0	
8,000 Lancs. & Yorks. Ry. 3% Debenture Stock . .	226 10 0	
6,000 London & N.W. Ry. 3% Debenture Stock . .	169 17 6	
9,600 Midland Ry. 2½% Debenture Stock . .	226 10 0	
New Purchase.		
3,000 2½% Consols . . .	0 0 0	
	1,853 19 6	
£64,600 Nominal or par value.		
— Rents—No. 27 Great George St.	1,061 12 1	
— Examination Fees	500 6 6	
— Interest on Deposit	68 6 1	
— Memorial to the late Dr. Pole	50 0 0	
— Miscellaneous	3 19 6	
		23,314 6 8
Carried forward		£29,789 4 3

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from the 1ST APRIL, 1901, *to the* 31ST MARCH, 1902.

EXPENDITURE.

Cr. GENERAL EXPENDITURE.

	£. s. d.	£. s. d.	£. s. d.
By House and Establishment Charges:—			
Repairs:—General	357 3 9		
Architect's Fees	96 10 0		
		453 13 9	
Repairs:—No. 27 Gt. George St.	380 8 5		
Rent of No. 27 Great George Street	600 0 0		
Agent's Charges for letting Offices and Surveyor's Fees	60 19 6		
		1,041 7 11	
Rates and Taxes:—The Institution	1,016 13 4		
No. 27 Gt. George St.	212 11 7		
		1,229 4 11	
Insurance:—The Institution	85 5 0		
No. 27 Gt. George St.	4 12 0		
		89 17 0	
Fixtures and Furniture		588 17 10	
Lighting, Warming and Ventilating:—			
The Institution	337 2 1		
No. 27 Gt. George St.	9 9 0		
		346 11 1	
Charges for Water (including lifts), Rent of Telephone, &c.	101 13 0		
Charges for Water, No. 27 Gt. George St.	19 8 6		
		121 1 6	
Refreshments at Meetings		91 17 0	
Assistance at Meetings		20 17 8	
Students' Meetings (including refreshments), Donation to Annual Dinner, and Visits		334 7 8	
Household Expenses		535 9 0	
			4,853 5 4
— Postages, Telegrams, and Parcels		358 3 11	
— Stationery and Printing		1,144 9 5	
— Watt Medals		4 15 0	
— Stephenson Medals		4 15 0	
— Diplomas		16 10 0	
— Annual Dinner (part 1902)		52 16 0	
— Conversazione		1,156 7 7	
			2,737 16 11
— Salaries		3,112 10 0	
— Clerks, Messengers, and Housekeeper		1,282 5 10	
— Retiring Allowances and Donations		1,269 0 0	
			5,663 15 10
— Library:—Books and Periodicals		269 18 1	
Binding		1 3 0	
Revision of Catalogue (on account)		200 0 0	
			471 1 1
Carried forward			£13,725 19 2

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ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS—*continued.*

Dr.

	£.	s.	d.
Brought forward	29,789	4	3

CAPITAL.

	£.	s.	d.	
To Admission-Fees	2,124	3	0	
— Life-Composition (Balance of)	10	10	0	
				2,134 13 0

Carried forward . .	£31,923 17 3

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from the 1ST APRIL, 1901, *to the* 31ST MARCH, 1902.

EXPENDITURE—*continued.*

Cr.				£.	s.	d.
	Brought forward			13,725	19	2
— Publications:—						
"Minutes of Proceedings," Vols. cxliv., cxlv., cxlvi. and cxlvii.	6,704	9	0			
Charters, By-Laws, and Lists of Members	199	4	6			
				6,903	13	6
By Professional Auditor's Fee	105	0	0			
— Legal Expenses	56	3	8			
— Contribution to the Expenses of the Committee on Standard Sections	250	4	6			
— Contribution to the Expenses of the International Engineering Congress, Glasgow (1901)	504	19	6			
— Examinations	513	15	2			
— Donation to Westminster Hospital	10	10	0			
				1,440	12	10
				22,070	5	6

CAPITAL.

	£	s.	d.
— Purchase of £3,000 2¾% Consols	2,840	13	6

Carried forward . . £24,910 19 0

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ABSTRACT *of* RECEIPTS *and* EXPENDITURE

Dr.

RECEIPTS—*continued.*

	£.	s.	d.
Brought forward	31,923	17	3

Trust Funds.

Telford Fund.

To Dividends:—1 year on

£.	s.	d.		£.	s.	d.	£.	s.	d.
5,439	11	0	2½% Consols	141	3	7			
3,299	2	0	Ditto (Unexpended Dividends) . . .	85	12	5	226	16	0
£8,738	13	0							

Manby Donation.

£250	0	0	Great Eastern Ry. 4% Irredeemable Guaranteed Stock				9	8	9

Miller Fund.

3,125	0	0	2½% Consols. . . .	81	1	11			
2,004	17	5	Ditto (Unexpended Dividends). . . .	52	0	8	133	2	7
£5,129	17	5							

Howard Bequest.

£551	14	6	2½% Consols				14	6	4

Trevithick Memorial.

£103	0	0	2½% Consols				2	13	5

Crampton Bequest.

£512	15	11	2½% Consols				13	6	3

"James Forrest" Lecture and Medal Fund.

£372	0	0	South-Eastern Ry. 5% Debenture Stock . .				17	11	2

Palmer Scholarship.

1,381	1	6	Metropolitan 3% Stock	39	0	5			
115	4	7	Ditto (Unexpended Dividends) . . .	3	3	6	42	3	11
£1,496	6	1							

John Bayliss Bequest.

			Amount Bequeathed .	1,000	0	0			
£1,013	17	10	London County 3% Stock	21	9	9			
							1,021	9	9
								1,480	18	2
							£33,404	15	5

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from the 1ST APRIL, 1901, *to the* 31ST MARCH, 1902.

EXPENDITURE—*continued.*

Cr.

	£.	s.	d.	£.	s.	d.	£.	s.	d.
Brought forward							24,910	19	0
TRUST FUNDS.									
By Telford Premiums	202	19	3						
— Telford Medals	9	0	0						
				211	19	3			
— Manby Premium				14	5	9			
— Miller Prizes	82	6	11						
— Miller Scholarship	40	0	0						
				122	6	11			
— Crampton Prize				10	10	0			
— "James Forrest" Lecture (ninth)	12	14	11						
James Forrest Medal	2	15	0						
				15	9	11			
— Palmer Scholarship—									
1 year's dividend to Scholar	42	4	9						
— Purchase of £10 6 2 Metropolitan 3% Stock (unexpended dividend)	10	11	9						
				52	16	6			
— John Bayliss Bequest—									
Purchase of £1,013 17 10 London County 3% Stock				1,000	0	0			
							1,427	8	4
							26,338	7	4
— Balance, 31 March, 1902, viz.:—									
On Deposit				6,000	0	0			
Cash in the hands of the Treasurer				1,054	8	2			
" " Secretary				11	19	11			
							7,066	8	1
							£33,404	15	5

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STATEMENT OF INVESTMENTS HELD 31 MARCH, 1902.

Institution Investments.

£		£. s. d.	£. s. d.
5,000	2¾% Consols	Cost 4,808 12 7	
4,000	London County 3% Stock . . .	„ 4,000 1 0	
4,000	Manchester Corporation 3% Stock .	„ 4,085 1 0	
6,000	Metropolitan 3½% Stock . . .	„ 6,517 15 0	
6,000	Great Eastern Railway 4% Debenture Stock	„ 7,749 18 3	
8,000	Great Northern Railway 3% Debenture Stock	„ 7,642 16 4	
8,000	Great Western Railway 4% Debenture Stock	„ 10,547 5 0	
8,000	Lancashire and Yorkshire Railway 3% Debenture Stock	„ 7,452 14 8	
6,000	London and North Western Railway 3% Debenture Stock . .	„ 5,544 18 5	
9,600	Midland Railway 2½% Debenture Stock	„ 7,460 18 11	
61,600			65,810 1 2
	Original cost of the freehold of the Institution Premises and of the New Building, including buildings now removed . .		124,379 10 0

Note.—No value has been attached, for the purpose of this statement, to the Books, Furniture, Fittings, Pictures, &c., in the Institution Building nor to the lease of No. 27 Great George Street.

Trust Funds Investments.

£. s. d.		£. s. d.
	Telford Fund.	
1,945 19 0	2¾% Consols—Acquired with a bequest of . .	2,000 0 0
3,479 12 9	do. Converted from Government Stocks bequeathed	Bequest.
13 19 8	do. Purchased with bonus on conversion cost	13 11 8
5,439 11 0		
3,299 2 0	do. Purchased with unexpended dividends	3,034 18 1
8,738 13 0		
	Manby Donation.	
250 0 0	Great Eastern Railway 4% Irredeemable Guaranteed Stock	Donation.
	Miller Fund.	
3,125 0 0	2¾% Consols—Acquired with a bequest of . .	3,000 0 0
2,004 17 5	do. Purchased with unexpended dividends	1,850 2 4
5,129 17 5		

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TRUST FUNDS INVESTMENTS—*continued.*

£.	s.	d.		£.	s.	d.
			Howard Bequest.			
551	14	6	2¾% Consols—Acquired with a bequest of . .	500	0	0
			Trevithick Memorial.			
103	0	0	2¾% Consols—Acquired with a presentation of .	100	0	9
			Crampton Bequest.			
512	15	11	2¾% Consols—Acquired with a bequest of . .	500	0	0
			"James Forrest" Lecture and Medal Fund.			
320	0	0	South Eastern Railway 5% Debenture Stock acquired with a subscription of	510	0	0
52	0	0	Ditto acquired with a subscription of £93 14*s.* 8*d.* and 19*s.* 4*d.* cash	94	14	0
372	0	0				
			Palmer Scholarship.			
1,381	1	6	Metropolitan 3% Stock bequeathed	Bequest.		
115	4	7	Ditto purchased with unexpended dividends . .	132	18	0
1,496	6	1				
			John Bayliss Bequest.			
1,013	17	10	London County 3% Stock acquired with a bequest of	1,000	0	0

J. H. T. TUDSBERY, *Secretary.*
14 *April*, 1902.

Examined with the Books and Securities and found correct.

(Signed) JOHN G. GRIFFITHS, F.C.A.
A. ROSS. } *Auditors.*

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MEDALS AND PREMIUMS AWARDED FOR THE SESSION 1900–1901, AND PRESENTED ON THE 5TH NOVEMBER, 1901.

FOR PAPERS READ AND DISCUSSED AT THE ORDINARY MEETINGS.

1. A George Stephenson Medal and a Telford Premium to Harry Edward Jones,[1] M. Inst. C.E., for his Paper on "Modern Practice in the Manufacture and Distribution of Gas."
2. Telford Medals and Premiums to George Andrew Hobson and Edmund Wragge, MM. Inst. C.E., for their joint Paper on "The Metropolitan Terminus of the Great Central Railway."
3. A Watt Medal and a Telford Premium to Joseph Husband, Assoc. M. Inst. C.E., for his Paper on "The Æsthetic Treatment of Bridge Structures."
4. A Telford Premium to James Thomas Ford, M. Inst. C.E., for his Paper on "The Present Condition and Prospects of the Panama Canal Works."
5. A Telford Premium to Leffert Lefferts Buck, M. Inst. C.E., for his Paper on "The Niagara Falls and Clifton Steel Arch Bridge."
6. Telford Premiums to William Harry Stanger, M. Inst. C.E., and Bertram Blount, Assoc. Inst. C.E., for their joint Paper on "The Rotatory Process of Cement Manufacture."
7. A Telford Premium to Walter James Doak, B.E., Assoc. M. Inst. C.E., for his description of the "Railway Bridge over the Fitzroy River at Rockhampton, Queensland."
8. A Crampton Prize to Edward Sandeman, M. Inst. C.E., for his Paper on "The Burrator Works for the Water-Supply of Plymouth."

FOR PAPERS PRINTED IN SECTION II OF THE PROCEEDINGS FOR THE SESSION 1900–1901.

1. A Telford Medal and a Telford Premium to Reginald Pelham Bolton, Assoc. M. Inst. C.E., for his Paper on "The High Office-Buildings of New York."
2. A Watt Medal and a Telford Premium to Joseph Emerson Dowson, M. Inst. C.E., for his Paper on "The Efficient Working of Gas-Plants for Engines."

[1] Has previously received Telford and Watt Medals and Telford Premiums.

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3. A George Stephenson Medal and a Telford Premium to William Thomas Clifford Beckett, M. Inst. C.E., for his description of "The Bridges over the Orissa Rivers on the East Coast Extension of the Bengal-Nagpur Railway."
4. A Manby Premium to Ernest Kilburn Scott, Assoc. M. Inst. C.E., for his Paper on "Coal-Cutting Machinery."
5. A Trevithick Premium to Thomas Alfred Hearson, R.N., M. Inst. C.E., for his Paper on "The Counterbalancing of Locomotives."
6. A Telford Premium to James Albert Wells Peacock, for his Paper on "Light Railways in Egypt."

FOR PAPERS READ BEFORE MEETINGS OF STUDENTS AT THE INSTITUTION.

1. The Miller Scholarship, tenable for 3 years, and the "James Forrest" Medal to Edward Vincent Clark, B.Sc., Stud. Inst. C.E., for his Paper on "The Theory of Cast-Iron Beams."
2. A Miller Prize to Charles Edward Inglis, B.A., Stud. Inst. C.E., for his Paper on "The Use of Geometrical Methods in Investigating Mechanical Problems."
3. A Miller Prize to Harry Egerton Wimperis,[1] B.A., Stud. Inst. C.E., for his Paper on "Cycle Resistance."
4. A Miller Prize to John Lionel Cridlan, Stud. Inst. C.E., for his Paper on "Automatic Coupling."
5. A Miller Prize to Fleetwood Keighly Peach, Stud. Inst. C.E., for his Paper on "Dock Gates."

FOR PAPERS READ BEFORE LOCAL ASSOCIATIONS OF STUDENTS.

1. A Miller Prize to George Hay Whigham, Stud. Inst. C.E. (Glasgow), for his Paper on "Light Railways."
2. A Miller Prize to Frank Coston Taylor, B.A., Stud. Inst. C.E. (Manchester), for his Paper on "The Development and Transmission of Hydraulic Power."
3. A Miller Prize to Arthur Cliffe Walsh, Stud. Inst. C.E. (Newcastle-upon-Tyne), for his Paper, "Construction and Working of Blockyards in connection with Seaham Harbour and Breakwater."
4. A Miller Prize to Harry Oscar Jones, Stud. Inst. C.E. (Manchester), for his Paper on "The Newent Waterworks of the Gloucester Corporation."

[1] Has previously received a Miller Prize.

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SUBJECTS FOR PAPERS, PREMIUMS, AND INSTRUCTIONS FOR PREPARING ORIGINAL COMMUNICATIONS.

THE COUNCIL of The Institution of Civil Engineers invite Original Communications on the Subjects included in the following List, as well as on other questions of professional interest. This list is to be taken merely as suggestive, and not in any sense as exhaustive. For approved Papers the Council have the power to award Premiums, arising out of Funds bequeathed for the purpose, the particulars of which are annexed.

LIST OF SUBJECTS.

RAILWAYS.

1. The Efficiency of Railways as affected by gauge, with reference to (*a*) the character of the traffic and climatic conditions; (*b*) utility for Military purposes.
2. The effects of Break of Gauge on the working expenses of a Railway, with reference to the cost of transfer, the liability to loss and breakage, and the necessity for increased rolling stock and separate repairing-shops.
3. The increase of Speed in express Travelling.
4. The use of Cast-Iron, Steel, and Wooden Sleepers; their suitability for various kinds of ballast, and the effects of salts contained in ballast, and of the sea air, upon them.
5. Rail-Depôts and Appliances for handling and stocking permanent-way materials.
6. The application of Machinery in large Railway Goods-Yards and Sheds.
7. The handling of Luggage by Machinery in large Passenger Stations.
8. Automatic Couplings and appliances for the Prevention of Accidents in Shunting.
9. The Maintenance, Strengthening, and Present Condition of Early Iron Bridges.
10. The Erection of Girders, with or without scaffolding.
11. The design and construction of Railway Carriages, having reference to (*a*) lavatory accommodation; (*b*) provision for refreshments; (*c*) sleeping accommodation.

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12. Standard and Metre-gauge rolling-stock on Indian railways, having reference to their relative capacity for (*a*) ordinary traffic; (*b*) Military transport and the carriage of heavy guns.
13. Street Railways, having reference to different systems of traction, viz., (*a*) steam; (*b*) cable conduit; (*c*) electric trolley; (*d*) electric rail contact; (*e*) electric conduit; (*f*) electric storage battery.

Waterways and Maritime Works.

14. The most economical Methods of Handling large masses of Excavation, as exemplified in modern canal construction.
15. The Measures necessary for the improvement of Canal Navigations.
16. The Dredging of Bars and Channels.
17. The Methods adopted in carrying out large Dock and Harbour Works, with descriptions of the Plant employed.
18. The Appliances for Dredging and for Removing Rock in deep water, with details of the time occupied in the various operations.

Machinery.

19. The Design and Construction of large Turbines.
20. The Forms of Turbine most suitable for Small Falls.
21. The most suitable Steam-power Equipments, and the size of units, for Electric-light stations.
22. The utilization of Wind-power.
23. The utilization of Wave- and Tide-power.
24. Modern Methods of Pumping compared with regard to cost and efficiency.
25. The Application of Compressed Air, Steam and Hydraulic power to Rock-drills and to other tools.
26. The Application of Steam-, Compressed-Air, Oil- and Gas-Engines to tractive purposes on common roads and on tramways.
27. The Theory and Development of the Compound Steam-Turbine.
28. The Strength of Steel Shafts, Tubes and Cylinders.
29. The most suitable Alloys for the Working Parts of Pumps for lifting Corrosive Liquids from mines, etc.
30. The Methods of Preventing or Arresting the Corrosion of Hydraulic Rams of large diameter.
31. The Methods of Testing the Lubricating Values of Oils, Greases, etc.

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32. The Use of the Die-press in workshop operations.
33. The Utilization of Heat (*a*) generated in the compression of air and other gases; (*b*) carried away by steam-engine condenser-water; and (*c*) contained in boiler-furnace flue-gases.
34. The Methods of Condensing Steam by the use of moderate quantities of water.
35. The Methods of removing Moisture from Steam, and of reducing losses by radiation from steam-pipes.
36. The Methods of removing Oil and other Impurities from Steam.
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40. The Sinking of Shafts through Various kinds of Strata, including Sand, and the methods of dealing with large inrushes of water.
41. Boring-Machinery suitable for different kinds of Rock, having regard to rapidity of progress and reliability in the various strata traversed.
42. Mining-Machinery, inclusive of Compound Engines for Winding purposes.
43. Mechanical Appliances for Coal-getting.
44. The use of Explosives Underground in different kinds of strata, as well as under water and in connection with dusty and fiery Mines.
45. The Mining of Thick and of Thin Seams of Coal, under different conditions of working with strong and weak roofs and floors.
46. The Underground Arrangements in Collieries.
47. Modern Coal-washing, Coking and By-product plant.
48. The Influence of Coal-dust in contributing to Colliery Explosions.
49. The Drainage of Mines by Pumping and by Tunnelling.
50. The extent and effects of Subsidence in different circumstances by the Pumping of Brine in Cheshire and elsewhere.
51. The Methods of Gold-mining in California and other Countries.
52. The Occurrence, Production and Uses of (*a*) Asbestos, (*b*) Arsenic, and (*c*) Mercury.

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53. The design, construction, erection and working of Modern Stamp Mills.
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55. Brine-pumping and the Manufacture of Common Salt.
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63. The Durability of Wrought-Iron and Steel Structures exposed to fresh, salt and brackish water.
64. Protection of Metallic Structures by paint and other substances.

Shipbuilding.

65. The Use of Steel of great tensile strength in Ships.
66. The present Limits of Speed at Sea.
67. The Relative Advantages of Single Screws, of Twin Screws, and of Triple Screws in large vessels.
68. The best position for Torpedo-Discharging Tubes on large vessels, with a fixed direction, or trainable.
69. The Use of Steam Turbines for the Propulsion of Ships.

Waterworks, Sewerage and Gasworks.

70. The Use of Steel in the Construction of large Tanks.
71. The Employment of Storage-Reservoirs in Irrigation and in the Conservation of Rivers.
72. Irrigation Works in the British Colonies.
73. Recent Practice in Filtration by Mechanical Means.
74. The Purification of Sewage by biological and chemical agencies.
75. The Production and Enrichment of Water-Gas.
76. The methods of Conveying and of Using Natural Gas.
77. The Use and Durability of Cast-iron Pipes and of other structures in contact with various soils.

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APPLICATIONS OF ELECTRICITY.

78. The Use of Electric Energy in working Mines.
79. The Utilization of Electric Energy for heating purposes.
80. The application of Electricity to Traction on Roads and Tramways.
81. The first cost and economy of operation of Electric Traction on Railways with heavy trains.
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83. The Use of Electric Motors for driving machines in textile factories and in engineering workshops.
84. The Use of Electric Motors for driving Pumps.
85. The Use of Electrical Machinery for lighting and for the transmission of power in warships and in the mercantile marine.
86. The Regulation of Electric Pressure in large Lighting Circuits as carried out at the engine, the dynamo, or the exciter.
87. The Progress of Telegraphy and Telephony at home and abroad.
88. The Application of Hertzian ether-waves, in Telegraphy, Telephony, the Steering of Torpedoes, etc.
89. The Electrolytic Action of Return Currents in Electrical Tramways on Gas- and Water-mains, and the best means of providing against Electrical Disturbances.

PREMIUMS.

1. The TELFORD FUND, left "in trust, the Interest to be expended in Annual Premiums, under the direction of the Council." This bequest (with accumulations of dividends) produces a gross amount of £235 annually.

2. The MANBY DONATION, of the value of about £10 a year, given "to form a Fund for an Annual Premium or Premiums for Papers read at the meetings."

3. The MILLER FUND, bequeathed by the testator "for the purpose of forming a Fund for providing Premiums or Prizes for the Students of the said Institution, upon the principle of the 'Telford Fund.'" This Fund (with accumulations of dividends) realises nearly £140 per annum. Out of this Fund the Council has established a Scholarship,—called "The Miller Scholarship of The

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Institution of Civil Engineers,"—and is prepared to award one such Scholarship, not exceeding £40 in value, each year, and tenable for three years.

4. The HOWARD BEQUEST, directed by the testator to be applied "for the purpose of presenting periodically a Prize or Medal to the author of a treatise on any of the Uses or Properties of Iron or to the inventor of some new and valuable process relating thereto, such author or inventor being a Member, Graduate, or Associate of the said Institution. The annual income amounts to nearly £15. It has been arranged to award this prize every five years commencing from 1877. The next award will be made in 1907.

5. The CRAMPTON BEQUEST of £500, free of legacy duty, has been invested in the purchase of £512 15*s.* 11*d.* 2¾ per cent. consols, and the income arising therefrom is now £13 14*s.* This trust is for the purpose of founding "a Prize to be called the 'Crampton Prize,' so that the interest of the said legacy shall be annually expended in a medal or books or otherwise . . . . for presentation to the Author of the best Paper on 'The Construction, Ventilation and Working of Tunnels of Considerable Length,' or failing that then on any other subject that may be selected."

6. The balance of the TREVITHICK MEMORIAL FUND, amounting to £100 0*s.* 9*d.*, has been accepted for a periodical Premium to be called after Richard Trevithick. This sum has been placed in £103 2¾ per cent. consols, upon which the interest is £2 15*s.* a year.

7. The JAMES FORREST MEDAL, founded in 1897, is endowed with the balance of a sum of money given by those who had served on the Council towards a presentation to Mr. Forrest on his retirement from the Secretaryship. The medal is awarded annually to a Student of the Institution who contributes the best Paper received from that class.

8. The JAMES PRESCOTT JOULE MEDAL is placed by the Trustees of the Endowment Fund at the disposal of the Council, in every third year, for award to a Student of the Institution, for the best Paper presented on an engineering subject, "preference being given to a Paper dealing with the transformation of energy." The medal will be at disposal next in 1903.

9. The BAYLISS PRIZE, of an annual value of about £28, established by a bequest under the will of the late Mr. John Bayliss, Assoc. Inst. C.E., is divided annually, at the end of each session, between the two Candidates who, being present or former Students of the Institution, obtain the highest marks in the Associate Membership Examinations held in the preceding October and February.

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The Council will not make any award unless a communication of adequate merit is received, but will give more than one Premium if there are several deserving memoirs on the same subject. In the adjudication of the premiums no distinction will be made between essays received from members of the Institution or strangers, whether Natives or Foreigners, except in the cases of the Miller, Howard, and Bayliss bequests and the James Forrest and James Prescott Joule medals, which are limited by the donors.

No Paper will be received from a Student in competition for a Premium when he has become qualified by age, viz. twenty-five years, for election into the Corporation. Students' Papers to be read before local Associations of Students of the Institution, in competition for Premiums, must be sent to the Institution, for registration, *before* being read.

Instructions for Preparing Original Communications.

In writing these Essays the use of the first person should be avoided. They should be legibly written on foolscap paper, on one side only, leaving a margin on the left side, in order that the sheets may be bound. Every Paper must be prefaced by an Abstract of its contents not exceeding 1,500 words in length.

Illustrations should be drawn on drawing- or tracing-paper, and figured dimensions should be introduced only where necessary. When an illustrated communication is accepted for reading, a series of Diagrams will be required so drawn and coloured as to be clearly visible at a distance of 60 feet. These diagrams will be returned.

Papers which have been read at the Meetings of other Societies, or have been published, will not be accepted. According to the By-laws every Paper presented to the Institution is deemed to be its property, and may not be published without the consent of the Council.

The Communications must be forwarded to the Secretary, from whom any further information may be obtained. There is no specified date for the delivery of MSS., as when a Paper is not in time for one session it may be dealt with in a subsequent one.

James Forrest, *Honorary Secretary*,
J. H. T. Tudsbery, *Secretary*.

The Institution of Civil Engineers,
Great George Street, Westminster, S.W.
July, 1902.

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Excerpt By-Laws, Article 3, Section XV.

"Every Paper, Map, Plan, Drawing, or Model, presented to the Institution shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same in any way and at any time they may think proper. But should the Council refuse or delay the publication of such Paper beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. Except as hereinbefore provided, no person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

Notice.

It has frequently occurred that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors have advanced somewhat doubtful theories, or have arrived at conclusions at variance with received opinions. The Council would therefore emphatically repeat that the Institution as a body must not be considered responsible either for the statements made, or for the opinions expressed in the Papers or in the consequent Discussions; and it must be understood that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the inquiry; but that such notice, or award, must not be regarded as an expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

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C.

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"Cassier's Magazine."
Cawley, G.
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Centralbureau für Meteorologie und Hydrographie im Grossherzogthum Baden.
Chamber of Mines, Victoria.
Chartered Institute of Patent Agents.
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"Colliery Guardian, The."
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"Contractors' Chronicle."
Cooper, Theo.
Cooper, W. R.
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Corthell, E. L.
Cowan, D.
Crugnola, G.
"Czasopismo Techniczne."

D.

Dalby, W. E.
Dalhousie College and University.
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Department of Mines, Melbourne.
Department of Mines, Perth.
Department of Mines, Queensland.
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"Deutsche Bauzeitung."
Directory Publishing Company.
"Domestic Engineering."
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E.

East India Association.
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Engineers' Club of Philadelphia.
Engineers' Society of Western Pennsylvania.
"Estates Gazette."

F.

Fidler, T. C.
"Fielden's Magazine."
Foster, C. Le N.
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Franklin Institute.
Frick, J.

G.

Gaudard, J.
"Génie Civil, Le."
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Hart, *Sir* R., *Bart.*
Hartley, *Sir* C.
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Hering, R.
Hill, L. M.
Hill, G. H.
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I.

"Ice and Cold Storage."
Imperial Institute.
Imperial Technical Society Russia.

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"Ingeniero, El."
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"Iron Age, The."
"Iron and Coal Trades Review, The."
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J.

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"Literary News."
Liverpool Engineering Society.
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Longmans, Green and Company.
Lupton, A.
Lürmann, F. W.

M.

MacColl, H.
McCormick, J. M.
McGill College and University, Montreal.
McKinney, H. G.
"Machinery Market."
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Magyar Mérnök-és Épitész.
Malan, E. de M.
Malo, L.
Manchester Association of Engineers.
Manchester Literary and Philosophical Society.
Manchester Ship Canal Company.
Manchester Steam Users' Association.
"Marine Engineer."
"Mariner."
Martin, A. J.
Massachusetts Institute of Technology.
Massachusetts State Board of Health.
Mawbey, E. G.
Maxwell, W. H.
Mayne, C.
"Mechanical Engineer."
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Mersey and Irwell Joint Committee.
Mersey Docks and Harbour Board.
Meteorological Department of the Government of India.
Meteorological Office, Bombay.
Meteorological Office, Calcutta.
Meteorological Office, London.
Meteorological Service of Canada.
Metropolitan Board of Water Supply and Sewerage, Sydney.
Metropolitan Water Board, Boston, U.S.A.
Michigan University.
Midland Institute of Mining, Civil and Mechanical Engineers.
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Mines and Water Supply Department, Melbourne.
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Ministère de l'Agriculture, Paris.
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Ministère du Commerce, Paris.
Ministerie van Waterstaat, Handel en Nijverheid.
Mitchell, C., and Company.
Mittler, E. S., and Son.
"Model Engineer, The."
Moncrieff, J. M.
Montreal, City Surveyor.
Morison, G. S.
Morton, D. H.
Munce, J.
Murray, R. A. E.
Muthesius, H.

N.

Nagao, H.
Nares, *Vice-Admiral Sir* G. S.
National Physical Laboratory.
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Naval Attaché, French Embassy.
Navy Department, U.S.A.
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Nichols, O. F.
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North-East Coast Institution of Engineers and Shipbuilders.
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O.

O'Connor, C. Y.
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Ordnance Committee.
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"Paper Maker."
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Pharmaceutical Society of Great Britain.
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Philosophical Society of Glasgow.
"Plumber and Decorator."
"Politecnico, Il."
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"Przegląd Techniczny."
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Puig de la Bellacasa y Sanchez, N.

Q.

"Quarry, The."
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Queen's College, Galway.
"Queen's Quarterly."
Quinette de Rochemont, *Baron*, E. T.

R.

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Railroad Commissioners of Massachusetts.
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Reade, T. M.
Reale Accademia dei Lincei, Rome.
Reale Instituto d'Incoraggiamento di Napoli.
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Regio Ispettorato Generale delle Strade Ferrate.
Rendel, W. W.
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Rickman, T. M.
Rio de Janeiro Observatory.
Ripper, W.
Robertson, L. S.
Robinson, J. C.
Rose, B. J.
Rowe, S. M.
Royal Agricultural Society of England.
Royal Artillery Institution.
Royal College of Surgeons.
Royal Colonial Institute.
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Royal Society of Edinburgh.
Royal Society of London.
Royal Society of New South Wales.
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Royal United Service Institution.
Royal University of Ireland.
Russell, S. A.
Rust, C. H.

S.

Sächsischer Ingenieur- und Architekten-Verein.
Salis, H. R. de.
Sandberg, C. P.
Sanitary Institute.
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Saxby and Farmer, Limited.
Schreiber, C.
Schulz, —.
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Sinigaglia, F.
Smee, A. H.
Smithsonian Institution.
Sociedad Científica Argentina.
Società degli Ingegneri e degli Architetti in Torino.
Società degli Ingegneri e degli Architetti Italiani.
Société d'Encouragement pour l'Industrie nationale.
Société de l'Industrie minérale de St. Etienne.
Société des Ingénieurs civils de France.
Société industrielle de Mulhouse.
Société scientifique industrielle de Marseille.
Société technique de l'Industrie du Gaz en France.
Society of Arts.
Society of Chemical Industry.
Society of Engineers.
South African Philosophical Society.
South Australian Railways Commissioner.
South Australian School of Mines and Industries.
South Wales Institute of Engineers.
Southey, F.
Spolku Architektů a Inženýrů v království Českém.
Sprague, F. J.
Stanley, W. F.
State Agricultural College of Colorado.
Stayton, G. H.
Stirling, J.
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Stoney, G. G.
Stonyhurst College Observatory.
Street Department, Boston, U.S.A.
"Street, The."
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Strickland, T. P.
Stromeyer, C. E.
Struthers, J.
Suplee, H. H.
Surgeon-General, U.S. Army.
Survey Department, Ceylon.
Survey of India Department.

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Surveyors' Institution.
Svenska Teknologförening.
Sydney Observatory.
Sydney University.

T.

Tasmanian Government Railways Department.
Technischer Staatslehranstalt in Chemnitz.
Teknisk Forening.
Thomason Civil Engineering College, Roorkee.
Thompson, A. G.
Thomson, A. W.
Thomson, T. F.
Thrupp, E. C.
Thwaite, B. H.
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Tudsbery, J. H. T.

U.

Uhagon, R. de.
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United States Bureau of Steam Engineering.
United States Coast and Geodetic Survey.
United States Department of Agriculture.
United States Department of Labour.
United States Geological Survey.
United States Naval Institute.
United States Naval Observatory.
United States Ordnance Department.
United States Patent Office.
University College, Bristol.
University College, Dundee.
University College, London.
University College, Nottingham.
University College of South Wales and Monmouthshire.
University of Wales.
University College, Sheffield.
Unwin, W. C.
Utah Agricultural College.

V.

Verein deutscher Eisenhüttenleute.
Verein deutscher Ingenieure.
Verein für Eisenbahnkunde zu Berlin.
Vernon-Harcourt, L. F.
Victoria University, Manchester.
Victoria University, Toronto.
Victorian Institute of Surveyors.
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W.

Wagner, C. A.
Wallace, J. F.
Wallis, H. S.
Walther-Meunier, —.
War Department, U.S.A.
Warbrick, J. J.
Warren, W. H.
"Water."
Werther, G.
West, A. A.
Western Society of Engineers, Chicago.
Wheeler, W. H.
Whipple, G. C.
Whitaker, W.
Whyte, P.
Willcocks, W.
Wollheim, A.
Wolverhampton Free Library.
Wood, F.
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Y.

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Committee on Tabulating the Results of Steam-Engine and Boiler Trials.

Members of the Committee:

Captain H. Riall Sankey, *Chairman.*

Sir Frederick J. Bramwell, Bart.	Sir Guilford L. Molesworth, K.C.I.E.
H. R. J. Burstall.	A. E. Seaton.
Bryan Donkin (the late).	A. B. Wilson.
Alex. B. W. Kennedy, LL.D.	C. J. Wilson.
Michael Longridge.	

Professor T. Hudson Beare, *Honorary Secretary.*

Report of the Committee.

To the Council of the Institution of Civil Engineers.

Gentlemen,

Your Committee now have pleasure in submitting their final Report upon the work they have been engaged upon since their appointment on 29 June, 1897. It will be in the recollection of the Council that, owing to the long illness and death of the first Chairman, Sir William Anderson, serious delays occurred in starting the work of the Committee.

On 25 April, 1901, your Committee submitted an interim Report in which they explained in some detail the principles which had guided them in drafting the forms for recording the observations required to be taken in making a trial of a complete plant, including all accessories. Since that date the forms originally drafted have been tested by Dr. Kennedy in tabulating the results of trials made by the Admiralty Boiler Committee, and in consequence several modifications have been made, mainly with a view to simplification and condensation. The forms in which the heat balances were set forth have also been re-arranged.

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The draft forms[1] now presented are the result of careful consideration, and, having been tested practically, your Committee believe they will be likely to meet with general acceptance, and be adopted by members who may be called upon to carry out tests on boilers and steam-engines.

In simplifying the forms, your Committee have, however, not lost sight of the desirability of so arranging them as to be suitable not only for complete tests made for scientific purposes, but also for commercial tests, in which latter many of the observations required for the former purpose are not needed.

The draft forms sent with this Report have been left blank, but your Committee would suggest that if the Council should see fit to recommend these draft forms as suitable for general use, they should be printed with the results of some selected trial filled in, and this your Committee would be prepared to do if so instructed by the Council.

As they stated in the interim Report, your Committee did not think their work would be complete if they simply prepared a draft set of forms on which the observations, results, etc., of tests could be recorded. They have therefore devoted a considerable amount of time, both at the meetings held in London and during the trials they conducted at Rugby and Belfast, to the laying down of rules as to the best methods of carrying out tests, and ascertaining the most suitable apparatus for use in such trials.

The result of this investigation is set forth in the two Appendixes which accompany the draft forms sent with this Report. Appendix I. deals fully with the best methods of carrying out the various observations required both in an ordinary commercial test and also in the more extensive series required in a scientific test of a complete plant. Your Committee have also described in this Appendix some of the more important apparatus needed in such tests and the methods of calibrating and checking their accuracy.

Appendix II. explains the manner in which it is intended that the draft forms should be filled in, the kind of information which should be inserted in places where more than the result of some simple observation has to be recorded, and gives methods of working out the results of the trials.

Your Committee therefore hope that the draft forms and the accompanying Appendixes will form a standard as to the best method of carrying out and recording engine and boiler trials.

[1] These Forms will be prepared for general use as soon as possible.—Sec. Inst. C.E.

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In conclusion, your Committee would draw attention to the fact that two points have arisen during their work which they have found it impossible to deal with satisfactorily. These points are:—

(*a*) The proper place or places to collect samples of furnace gases, and the most satisfactory way of obtaining a fair average sample.

(*b*) The methods of determining the dryness of steam.

Your Committee will be happy to deal with these points in a further special Report unless the Council prefer to appoint a special Committee or Committees to undertake their consideration.

H. RIALL SANKEY,
Chairman.

T. HUDSON BEARE,
Hon. Secretary.

14 April, 1902.

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Committee on Tabulating the Results of Steam-Engine and Boiler Trials.

Members of the Committee:

Captain H. Riall Sankey, *Chairman.*

Sir Frederick J. Bramwell, Bart.	Sir Guilford L. Molesworth, K.C.I.E.
H. R. J. Burstall.	A. E. Seaton.
Bryan Donkin.	A. B. Wilson.
Alex. B. W. Kennedy, LL.D.	C. J. Wilson.
Michael Longridge.	

Professor T. Hudson Beare, *Honorary Secretary.*

Interim Report of the Committee.

To the Council of the Institution of Civil Engineers.

Gentlemen,

Your Committee had fully expected to be able to send in their final Report in time for the Annual General Meeting on 30 April, but at the last moment discussion arose on certain points, and it was felt to be hopeless to settle these points in time for a complete Report to be drafted. The Committee, however, determined to send an interim Report, and inform the Council how far they have proceeded with the work entrusted to them.

Your Committee have drafted forms for recording the observations required to be taken in making a trial of a complete steam plant including all accessories, and these forms further provide for entering the results of the trial and for establishing a heat balance. The forms are also so framed that where a test of a part only of a complete plant is necessary (for example, the boiler or engine alone), the forms dealing with that single part are complete in themselves, and enable a complete record of the test to be tabulated, and heat balance established.

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Your Committee are of opinion that the tabular forms should provide both for complete tests made for scientific purposes and for commercial tests, where of necessity many of the observations required for the former class of test are not made. They have endeavoured to provide for this by printing the forms in different type, the less important observations being shown in small type.

After holding several meetings in London to discuss and decide upon the way in which the tabular results should be arranged, your Committee decided to make two trials in order to test for themselves the methods they had provisionally adopted for recording results. By the kind permission of Messrs. Willans and Robinson, one of these was made at Rugby, and the other took place at Comber, near Belfast, where Messrs. J. Andrews & Co. were good enough to place the whole of their steam-plant at the disposal of the Committee for the purposes of the test. The Committee would desire to thank these two firms and the various members of their staffs for the valuable help they thus gave the Committee.

As a result of these trials, modifications in some respects have been made in the provisionally adopted forms, and the final consideration of the amended forms—copies of which accompany this Report—is all that now remains to be done.

The Committee desire to mention that they have entered in the draft forms now sent for your information the results of the Belfast trial, and in order to make the forms more complete they have also filled in assumed figures for certain parts of the plant where no observations could be made at Belfast. They consider that the principles which have guided them in drafting these forms will be more readily understood if the Council have before them sets of the draft forms completely filled up. The assumed figures thus filled in are printed in small italics to distinguish them from the actual figures obtained at the trial.

Your Committee did not think their work would be complete if they confined themselves to drafting the forms on which the observations, results, etc., of tests should be recorded. They are therefore preparing, in addition, three Appendixes, one giving information as to the best methods of carrying out tests and the apparatus which should be used, another dealing fully (with numerical examples) with the calculations necessary in order to obtain the heat balances and other deductions from the tests, and a third describing how it is intended that the suggested forms should be filled in. These Appendixes are nearly complete, and accompanying this Report is an uncorrected proof of Appendix I., which will enable the Council to judge of their scope.

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In conclusion, your Committee wish to draw the attention of the Council to two or three points which have arisen during this inquiry, and as to which they feel that any attempt on their part to deal with them would unduly delay the Report. These points are :—

(*a*) The proper place or places to collect samples of furnace-gases.

(*b*) The methods of determining the dryness of steam.

(*c*) The proper method of determining the calorific value of fuels.

Your Committee will be happy to deal with these points unless the Council prefer to appoint a special Committee or Committees to undertake the work.

Your Committee hope to furnish their complete report and its accompanying draft forms and Appendixes early in this summer.

H. Riall Sankey,
Chairman.

T. Hudson Beare,
Hon. Secretary.

25 April, 1901.

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I.—Trial of a Steam Plant at _____ Made on the _____ 19__

BOILER. Sheet I. General Description and Dimensions.

Type of Boiler. _____ Made by _____

Maker's rating of the output of the Boiler _____ lbs. of steam per hour.

Pressure for which Designed _____ lbs. per sq. inch (gauge).

Test made at an output of _____ lbs. of steam per hour, at a pressure of _____ lbs. per sq. inch (gauge) in the presence of . . . . . .

Object of Trial _____

Reference Number.	General Description of Boiler and Leading Dimensions.
1	
2	Method of starting and stopping the test
3	Method of stoking and average thickness of fire
4	Production of draught
5	Chimney, height ___ ft. Area at bottom ___ sq. ft.; top ___ sq. ft.
6	Total grate surface (excluding dead plate) . . . sq. ft.
7	Percentage of grate area occupied by air spaces between bars . . . . .
8	Total effective heating surface (fire box ___ sq. ft., tubes ___ sq. ft.) . . . . . sq. ft.
9	Capacity of water space . . at ___ inches c. ft.
10	,, steam space . . in gauge glass ,,
11	Area of water surface in boiler sq. ft.

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II.—Trial of a Steam Plant at _____ Made on the _____ 19___

BOILER. Sheet II. DATA DEDUCED FROM OBSERVATIONS.

Reference Number.	Particulars of Observations.	——	Remarks.
12	Duration of trial . . . . . hours		
	FUEL.		
13	Short description		
14	Fired per hour . . . . . lbs.		
15	Analysis by weight of dried fuel—Carbon . . per cent.		
	„ „ „ Hydrogen . „ „		
	„ „ „ Sulphur . „ „		
	„ „ „ Ash . . „ „		
	„ „ „ Oxygen . „ „		
	„ „ „ Other matters „ „		
16	Moisture in fuel as fired . . . . . per lb.		
17	Calorific value of dried fuel . . . . B.Th.U. per lb.		
18	Carbon value per lb. of dried fuel		
	ASH AND CLINKER.		
19	Total per hour . . . . . lbs.		— per cent. of total fuel fired.
20	Carbonaceous matter in ash per hour . . . . lbs.		
	FLUE GASES.	By Vol. By Weight.	
21	Analysis of dry flue gases—Carbonic Acid . per cent.		
	„ „ „ Carbonic Oxide . „ „		
	„ „ „ Oxygen . . . „ „		
	„ „ „ Nitrogen by difference „ „		
22	Average temperature leaving boiler flues . . . °F.		
23	Mean specific heat of products of combustion . B.Th.U.		
	AIR AND DRAUGHT.		
24	Temperature of outside air . . . . . °F.		
25	Barometric pressure (____inches mercury) lbs. per sq. in.		
26	Pressure in ash pit (if forced air supply) inches of water		
27	„ over fire . . . . . „ „		
28	Draught at gas exit from boiler . . . „ „		
29	„ base of chimney . . . . „ „		
30	Weight of steam per hour used in producing draught lbs.		
	FEED WATER.		
31	From pump, economiser or feed heater per hour . lbs.		
32	Temperature of feed to boiler . . . . . °F.		
	STEAM.		
33	Gauge pressure . . . . . lbs. per sq. in.		
34	Absolute pressure . . . . . „ „ „		
35	Total moisture in steam . . . . . per lb.		
36	Temperature of saturation . . . . . °F.		

NOTE.—When jacket condensed steam and re-heater condensed steam are returned direct to the boiler, the weight of each, returned per hour, should, if possible, be determined, and also the temperatures at which they enter the boiler. The blank lines are intended for use in such cases, and for any other observations which it may be desired to record.

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III.—Trial of a steam plant at _____ Made on the _____ 19__

BOILER. Sheet III. HEAT ACCOUNT AND DEDUCTIONS.

Reference Number.	——	B.Th.U.	Per Cent.
	HEAT ACCOUNT (per lb. of dried fuel).		
37	Total heat value of 1 lb. of dried fuel . . .		
38	Heat transferred to the water (*thermal efficiency*)		
39	Heat carried away by products of combustion .		
40	Heat carried away by excess air		
41	Heat lost in evaporating and in superheating moisture mixed with fuel		
42	Heat lost by incomplete combustion		
43	Heat lost by unburnt carbon in ash		
44	Balance of heat account. Errors of observation, and unmeasured losses, such as—those due to radiation, escape of unburnt hydrocarbons, superheating moisture in air, loss in hot ashes, etc.		
	Total . .		
	DEDUCTIONS.		
45	Heat transmitted per square foot of heating surface per hour	B.Th.U.	
46	Weight of fuel fired per square foot of grate per hour	lbs.	
47	Weight of dried fuel fired per square foot of grate per hour	lbs.	
48	Water evaporated per lb. of fuel as fired . .	lbs.	
49	Equivalent evaporation from and at 212° F. per lb. of fuel as fired	lbs.	
50	Water evaporated per lb. of dried fuel . . .	lbs.	
51	Equivalent evaporation from and at 212° F. per lb. of dried fuel	lbs.	
52	Equivalent evaporation per lb. of carbon value of dried fuel from and at 212° F.	lbs.	
53	Weight of feed, from and at 212°F., per square foot of heating surface per hour	lbs.	
54	Velocity of steam leaving water surface. . .	feet per second	
55	Air used per lb. of dried fuel.	lbs.	
56	Ratio of air used to air theoretically needed		

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IV.—Trial of a Steam Plant at _____ Made on the _____ 19___

ECONOMISER AND SUPERHEATER. Sheet I.

GENERAL DESCRIPTION AND DIMENSIONS.

Reference Number.		
	ECONOMISER.	
57	General description of Economiser, and arrangement of flues, &c.	
58	Heating surface of economiser . . . . . sq. feet.	
	SUPERHEATER.	
59	General description of superheater and of method of heating it	
60	Heating surface . . . . . sq. feet.	

DATA DEDUCED FROM OBSERVATIONS.

	ECONOMISER. (Heating of feed by flue gases.)	Abstract of Observations.	Remarks.
61	Weight of feed water entering economiser per hour . lbs.		
62	Temperature of feed into . °F.		
63	,, ,, out of °F.		
64	,, of flue gases into °F.		
65	,, ,, ,, out of °F.		
66	Analysis of dry flue gases leaving economiser . . . . . Carbonic acid . . per cent. Carbonic oxide . . ,, Oxygen . . . . ,, Nitrogen (by difference) ,,	By volume. By weight	
67	Mean specific heat of flue gases leaving economiser . B.Th.U.		
	SUPERHEATER.		
68	Weight of steam entering superheater per hour . . . lbs.		
69	Steam pressure (absolute) into lbs. per sq. inch.		
70	Moisture of steam into per lb.		
71	Temperature of steam into °F.		
72	,, ,, out of °F.		
73	,, of flue gases into °F.		
74	,, ,, ,, out of °F.		
75	Analysis of dry flue gases leaving superheater . . . . . Carbonic acid . . per cent. Carbonic oxide . . ,, Oxygen . . . . ,, Nitrogen (by difference) ,,	By volume. By weight	
76	Mean specific heat of flue gases out of . . . . . B.Th.U.		

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V.—Trial of a Steam Plant at_____ Made on the_____19__

ECONOMISER AND SUPERHEATER. Sheet II.

HEAT ACCOUNT AND DEDUCTIONS.

Reference Number.	HEAT ACCOUNT (per lb. of dried fuel).	B.Th.U.	Per Cent.
	ECONOMISER.		
77	Heat received from boiler flues, in gases and steam, per lb. of dried fuel (reckoned from air temperature)		
78	Heat transferred to the water (*efficiency of economiser*)		
79	Heat carried off in the chimney gases . .		
80	Balance of heat account, including errors of observation and difference of heat contained in brickwork at beginning and end of tests, etc.		
	Total . .		
	SUPERHEATER.[1]		
81	Heat received from flue gases and steam per lb. of dried fuel (reckoned from air temperature		
82	Heat transferred to steam (*efficiency of superheater*)		
83	Heat carried off in the chimney gases . .		
84	Balance of heat account, including errors of observation, etc.		
	Total . .		
	DEDUCTIONS.		
85	Heat transmitted per square foot of heating surface of economiser per hour	B.Th.U.	
86	Heat transmitted per square foot of heating surface of superheater per hour	B.Th.U.	
87	Efficiency of boiler, economiser, and superheater combined	per cent.	

[1] parately fired, enter results on boiler form.

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VI.—Trial of a Steam Plant at _____ Made on the _____ 19__

ENGINE. Sheet I. GENERAL DESCRIPTION AND DIMENSIONS.

Type of Engine { _____ Made by { _____

Maker's rating of the power _____ I.HP. at _____ revs. per min. and _____ lbs. per sq. inch, stop valve pressure.

Test made at _____ I.HP., in the presence of { _____

Character of load _____

Object of trial _____

Reference Number.			H.P.	I.P.	—	L.P.
88	General description of engine _____					
89	Type of valves _____					
90	How governed _____					
91	Method of measuring steam consumption _____					
	Particulars of cylinders:—					
92	Diameters of cylinders	inches				
	,, ,, piston-rods . . .	,,				
	Strokes of pistons	,,				
93	Volumes swept by pistons per stroke (mean of two ends) . .	c. feet				
94	Clearance volumes per stroke (mean of two ends)	per cent.				
95	Clearance surfaces per stroke (mean of two ends)	sq. feet				
96	Proportion of clearance surfaces jacketed	per cent.				
97	Proportion of barrel surfaces jacketed	per cent.				
98	Receiver or reheater or interheater, volume of	c. feet				
99	Receiver or reheater or interheater, heating surface of	sq. feet				

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VII.—Trial of a Steam Plant at_____ Made on the _____19__

ENGINE. Sheet II. DATA DEDUCED FROM OBSERVATIONS.

Reference Number.	Particulars of Observations.	—	Remarks.
100	Duration of trial . . . hours		
101	Barometric pressure (atmosphere) ____inches of mercury = lbs. per sq. inch.		
	STEAM.		
102	Weight entering HP. cylinder per hour . . . . . lbs.		
103	Weight passing through jackets per hour . . . . . lbs.		
104	Pressure by gauge . at boiler side of stop valve. Pressure (absolute) lbs. per sq. inch		
105	Temperature of steam at boiler side of stop valve . . °F.		
106	Moisture in steam at boiler side of stop valve . . . . per lb.		
107	Drainage from jackets per hour lbs.		
108	Temperature of jacket drain water at exit from engine °F.		
	EXHAUST STEAM.		
109	Pressure (absolute) at exit from engine . . lbs. per sq. inch		
110	Corresponding temperature of saturated steam . . . °F.		
111	Temperature at exit from engine °F.		
	POWER.		
112	Mean effective pressure— In HP. cylinder lbs. per sq. inch		corresponding I.HP. =__
	In I.P. cylinder lbs. per sq. inch		,, ,, =__
	In L.P. cylinder lbs. per sq. inch		,, ,, =__
113	Mean pressures referred to L.P. cylinder . . lbs. per sq. inch		
114	Mean area of L.P. cylinder sq. ins.		
115	Revolutions (by counter) per min.		
116	Piston speed in L.P. cylinder in feet . . . . . per min.		
117	Indicator horse power . . I.HP.		
118	Brake horse power . . B.HP.		
119	Mechanical efficiency per cent. $= \frac{\text{B.HP.}}{\text{I.HP.}} \times 100$		

NOTE.—Blank lines are left in this form for filling in observations which may be taken in engines using reheaters or interheaters, and for recording such observations as the temperature range in the cylinders, pressures in the jackets, and any other observations which it may be specially desired to record.

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VIII.—Trial of a Steam Plant at _____ Made on the _____ 19___

ENGINE. Sheet III. HEAT ACCOUNT AND DEDUCTIONS.

Reference Number.	——	B.Th.U.	Per Cent.
	HEAT ACCOUNT (from 32° F.)		
120	Gross heat supply entering engine per minute		
121	Heat equivalent of indicator horse power . . . . . " "		
122	Heat leaving engine in jacket drain . . . . . " "		
123	Heat leaving engine in exhaust steam . . . . . " "		
124	Balance of Heat Account (errors of observation, losses by radiation, etc.		
	DEDUCTIONS (reckoned from exhaust temperature).		
125	Heat supplied per minute per I.HP. . . . B.Th.U.		
126	Thermal efficiency		
127	Heat theoretically required per minute by the "Institution of Civil Engineers' standard of comparison" per I.HP. (Rankine's cycle) . B.Th.U.		
128	Efficiency ratio		
129	Heat supplied per minute per B.HP. . . . B.Th.U.		
130	Pounds of steam used per I.HP. per hour . . . lbs.		

Remarks: _____

NOTE.—In engines using reheaters, interheaters, etc., the heat returned from them to the boiler should be entered in the heat balance on the "out"-side.

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IX.—Trial of a Steam Plant at _____ Made on the _____ 19__

ENGINE ACCESSORIES. Sheet I. [GENERAL DESCRIPTION AND DIMENSIONS.

Reference Number.	
	[CONDENSER.
131	General description of condenser _____
	FOR SURFACE CONDENSER.
132	Number of tubes . . . . .
133	External diameter of tubes. . . . . inches
134	Length of tubes between tube-plates. . feet
135	Effective area of cooling surface . . . sq. feet
	AIR PUMPS.
136	General description and method of driving _____
	CIRCULATING PUMPS.
137	General description and method of driving _____
	FEED HEATER.
138	General description of feed heater, and of connections to exhaust pipe, feed pump, and boiler connections:
139	Heating surface (if any) . . . . . sq. feet.
	STEAM PIPES.
140	General description of steam-pipe arrangements and of methods of draining them, kind of covering, etc.:
141	Diameter of main steam pipe
142	Length of main steam pipe

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X.—Trial of a Steam Plant at _____ Made on the _____ 19___

ENGINE ACCESSORIES. Sheet II. DATA DEDUCED FROM OBSERVATIONS.

Reference Number.	——	—	Remarks.
	CONDENSER.		
143	Cooling water passing through condenser per hour	lbs.	
144	Temperature of cooling water as it enters condenser	°F.	
145	Temperature of cooling water as it leaves condenser	°F.	
146	Exhaust steam entering condenser per hour.	lbs.	
147	Temperature of exhaust steam as it enters condenser	°F.	
148	Temperature of condensed steam as it leaves condenser	°F.	
149	Vacuum in condenser . .	inches of mercury / lbs. per square inch.	
	AIR PUMP.		
150	Effective volume displaced by air pump bucket per minute.	cubic feet.	
151	Indicator horse-power absorbed in pump .	I.HP.	
	CIRCULATING WATER PUMP.		
152	Effective strokes per minute or revolutions per minute if centrifugal.	. . .	
153	Indicator horse-power absorbed in the pump	I.HP.	
	[NOTE.—If the pumps are driven by an independent engine, the records of the tests of this engine should be filled up in an engine sheet.]		
	FEED HEATER (heating of feed by exhaust steam).		
154	Temperature of feed into	°F.	
155	„ „ „ out of.	°F.	
156	„ „ exhaust steam. . . .	°F.	
	FEED PUMP.		
157	Temperature of feed passing through pump	°F.	
158	Steam used by feed pump (if separately driven)	lbs. per hour.	
	STEAM PIPES.		
159	Steam pressure (absolute) in boiler . .	lbs. per sq. inch.	
160	Steam pressure (absolute) at engine stop valve	lbs. per sq. inch.	
161	Temperature of steam at boiler or at superheater end of pipe.	°F.	
162	Temperature of steam at engine stop valve	°F.	
163	Moisture in steam at exit from boiler . .	per lb.	
164	„ „ at engine stop valve .	per lb.	
165	Water collected from steam pipes per hour	lbs.	

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XI.—Trial of a Steam Plant at_____ Made on the_____19__

SUMMARY.

Rated power of the Plant_____ I.HP.

Test made at_____of the rated power, in the presence of {_____ _____ _____ _____

ECONOMY OF THE COMPLETE PLANT.

Reference Number.		
166	Total heat value of fuel fired in boiler and superheater per minute	B.Th.U.
167	Heat equivalent per minute of I.HP. developed	,,
168	,, ,, ,, ,, B.HP.	,, ,,
169	Percentage of heat utilized in I.HP.	,, per cent.
170	,, ,, ,, B.HP.	,, ,,
171	Coal fired per I.HP. per hour	lbs.

REMARKS: _____

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APPENDIX I.

Suggested Methods of Making the Measurements Required in Boiler and Steam-Engine Trials.

INTRODUCTION.

Some of the more reliable and accurate methods of measurement that are usually employed when carrying out boiler and engine trials have been collected together in this Appendix. The large majority of trials are undertaken to prove a guarantee of performance given by the maker to the user, and for such tests it is not necessary to measure the losses that occur. In other words, the principal measurements required are those that pertain to the weighing of the fuel and the determination of its quality, to the weighing of the water evaporated, and to the measurement of the power produced. The data thus obtained are sufficient to determine the thermal efficiency of a boiler or the British thermal units per indicator horse-power required by a steam-engine, or, more popularly but inaccurately expressed, the pounds of water evaporated per pound of coal, or the pounds of feed-water per indicator horse-power.

It is nevertheless desirable to measure the losses, at any rate the more important ones, because a valuable check is thus obtained on the accuracy of the trial. Such measurements consist in taking the temperature of the flue gases and analysing them, weighing the ash, etc.

The various measurements required for a trial divide themselves, therefore, into two groups, and can be tabulated as follows:—

Measurements Required to Determine the Thermal Efficiency of a Boiler.

Relating to Fuel.

(1) Rate of fuel-consumption.
(2) Sampling of fuel and determination of its calorific value, and of the moisture in it.

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Relating to Water evaporated.

(3) Rate of water-evaporation.
(4) Measurement of steam-pressure.
(5) Determination of the water present in the steam (dryness fraction).
(5*a*) If there is a superheater, the temperature of the steam.
(6) Measurement of the feed temperature.

Measurements required to determine losses.

(7) Measurement of temperature of the flue gases.
(8) Collection and analysis of the flue gases.
(9) Sampling and weighing of ashes.
(10) Chemical analysis of ashes, or determination of calorific value.
(11) Measurement of air-pressure.
(12) Radiation and leakage.

MEASUREMENTS REQUIRED TO DETERMINE THE THERMAL EFFICIENCY OF A STEAM ENGINE.

Relating to Steam.

(13) Measurement of rate of steam-supply by weight.
(14) Determination of water present in the steam (dryness fraction).
or (14*a*) Temperature of the steam if superheated.
(15) Pressure of the steam at the stop-valve.
(16) Temperature (or pressure) of the exhaust steam.

Relating to Power.

(17) Measurement of the indicator horse-power.
(17*a*) If possible, the brake horse-power should also be measured.

A variety of measurements are required in connection with the accessories of a steam plant. They are, however, similar to those tabulated above, and references will be found in the tabular forms to the methods of carrying them out explained in this Appendix.

The makers of boilers and steam-engines often require to make experiments to elucidate some particular point; the methods of carrying out such trials must obviously be addressed specially to the point in question, and no attempt therefore can be made to deal with such matters in this Appendix.

In many recent steam-engines a re-heater has been used, warmed by steam taken direct from the boiler, and the resulting hot water has been taken straight back to the water-space of the boiler, thus for[illegible]ed loop. Heat is thus supplied to the engine, the

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amount of which cannot be obtained by measurement of the feed, and if no account is taken of this heat a serious error, to the advantage of the engine, will be made. A similar case occurs if the jacket-steam is returned direct to the boiler. Attempts have been made to measure this supply of heat to the engine, but with only moderate success, and it is regretted therefore that it has not been found possible to give a description of a suitable method.

No. 1.—Starting and Stopping the Trial.

The best way of starting and finishing a boiler trial must be decided by the principal observer on the spot, because it is governed by the conditions under which the boiler has to work, but one of the following three methods may generally be used.

A. *First Method*, applicable when the rate of evaporation can be kept uniform throughout the trial.—The fires having been cleaned and made up a short time before it is intended to start the trial, and everything being in the ordinary working condition, the principal observer gives the signal by blowing a whistle to commence firing with fuel from the first bag or box of coal; at the same instant the feed-pump should be started upon the first measured tank of water, and the level of the water in the boiler and in the feed-water tank should be noted.

The time at which the above three things are done is taken as the *starting-time of the trial.* Throughout the trial the time of commencing and finishing each bag or box of coal and each tank of water must be carefully noted, and also the level of the water in the gauge-glass. While the trial is proceeding it is advisable if possible to plot[1] both the fuel and feed measurements to a time base, as in this way a most valuable check on the observations is obtained. The following diagram for coal consumption (*Fig. 1*) will more fully explain the method:—

If a fair line be drawn for the water and fuel observations so plotted the fuel and water used per hour is at once obtained. It will be noticed in the diagram that the effect of cleaning the fires is very definitely shown; by taking the fair lines on either side of this point and averaging them the bad effect of cleaning the fires on the accuracy of the results from a scientific point of view is eliminated. For practical purposes the effect of cleaning fires, stopping for dinner-hour, etc., has to be recorded.

[1] The weight of coal in a given charge should not be plotted over the time when it is fired, but over the time of firing the first shovelful of the next charge (see first sentence on p. 241).

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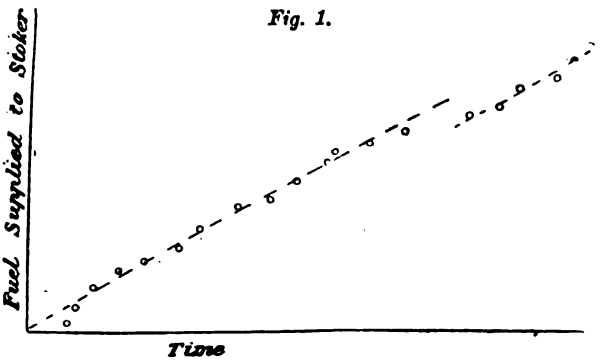
The fuel measurements may be stopped after about n hours run at the moment any bag or box of coal is finished, n being a multiple of the time it is possible to run the boiler without cleaning the fires. The grates should, of course, be cleaned and the fires made up previous to the stoppage as they were previous to the start, and similarly at about the same time the feed measurements may be stopped when any tank is finished. It is desirable that

Fig. 1.



the water-gauge level should be the same at the end as it was at the beginning; if this is not possible the correction should be made on the diagram before drawing the fair line.

The weight of water corresponding to a difference of level of each $\frac{1}{10}$ inch in the boiler should be determined before the trial begins, in order that the correction to the feed measurements may be plotted as the trial proceeds.[1] In the diagram (*Fig. 2*) the full line shows the rate at which the feed was pumped into the boiler,

[1] It should be remembered that *when the final is higher than the initial level the weight of water to be deducted from* the measured feed is not the weight of the layer of water contained between the two levels, but an equivalent weight which, if converted from water at feed temperature into steam at boiler pressure, would have absorbed the same quantity of heat as was required to heat the layer of water between the gauge levels from the temperature of the feed to the temperature of the steam, but not to evaporate it.

If W be the weight of water between the two gauge levels, t and T the temperatures of the feed and of the steam respectively, h the heat of evaporation, commonly called the latent heat of 1 lb. of water at temperature T, and w the equivalent weight to be deducted from the feed, then

$$w = \frac{W(T - t)}{T - t + h}.$$

When the final level is lower than the initial the weight to be added to the measured feed is of course the actual weight W of the layer of water contained between the two gauge levels at temperature T.

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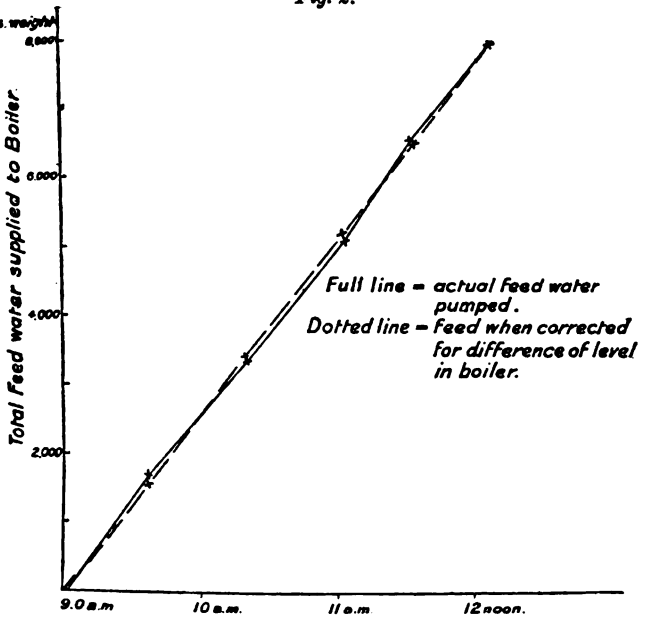
the dotted line the rate corrected for differences of level in the boiler, or the rate of water evaporation.

Fig. 2.



B. *Second Method.*—The fires are lighted long enough before the intended time for commencing the trial to bring everything into uniform condition. If the boiler has been working for some time, all the fires are thoroughly cleaned and got into good order, and the rate of evaporation and the corresponding feed are then adjusted as nearly as possible to the intended rate. About a quarter of an hour before the time fixed for the start sufficient water is put into the feed-tank to last for this interval of time; the firing of the boiler is stopped, any coal lying near the boiler or on the firing-plate being swept up and removed. The fire is now examined carefully from time to time and raked up to close any holes, and the pressure-gauge is carefully watched and noted at short intervals, until, at a fairly distinct moment, the pressure begins to drop rapidly. This is the moment at which the heat supplied from the furnace becomes insufficient to maintain the rate of evaporation, and this instant is noted as the beginning of the trial, and the following operations are then effected:—

(*a*) The feed-pumps are stopped.

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(*b*) The height of the water in the boiler gauge-glass is noted. (It is a good plan to make a mark on a smooth piece of wood fixed to the back of the gauge-glass.)

(*c*) All ashes are cleaned out.

(*d*) The first bag or box of coal is emptied on to the floor and stoking is recommenced.

(*e*) The level of the water in the feed-water tank is noted, and the feed-pumps are again started.

Throughout the trial every endeavour should be made to keep the rate both of evaporation and of the feed constant, and to maintain constant pressure in the boiler with the least possible variation of level in the height of the water in the gauge-glass. To attain this, great care is needed throughout the whole of the experiment.

Near the end of the trial, the last bag of coal having been emptied on to the floor and finally fired (care must be exercised to maintain the same rate of evaporation), and the water height in the gauge glass having been brought back to what it was at the beginning of the trial by regulation of the feed, the steam gauge is again carefully watched, and the instant at which it again begins to show a notable fall is taken as the time of the finish of the trial. It may be assumed that at this instant the furnace again ceases to supply sufficient heat to maintain the working pressure at the rate of evaporation which has been used during the trial, and that therefore the condition of the fire and of the boiler generally is the same as it was at the beginning of the trial.[1]

It will always be found best when running a trial by this method not to inform the stokers that it is intended to finish the trial at any given time, or they will probably unconsciously slacken the stoking. It will be noticed that by this method the precise moment of ending the trial is not predetermined, but it should preferably be made *later* than a previously fixed hour.

The time of throwing on the first shovelful of each of the weighed charges should be carefully noted, and it will probably be a check to stop the trial at an instant when the stokers are just about to begin throwing coal on to the fire from a new charge, as this is the time at which, in the judgment of the stoker, the last charge was as completely burnt as its predecessors. This instant of time will mark approximately the last spot on the straight part of the plotted

[1] The feed-pump should be at once shut off, and the feed-water tank filled to the same level as it was at the start, from one of the measuring-tanks, or else the level of the water in the feed-water tank when the pumps were shut off may be noted, as at the start.

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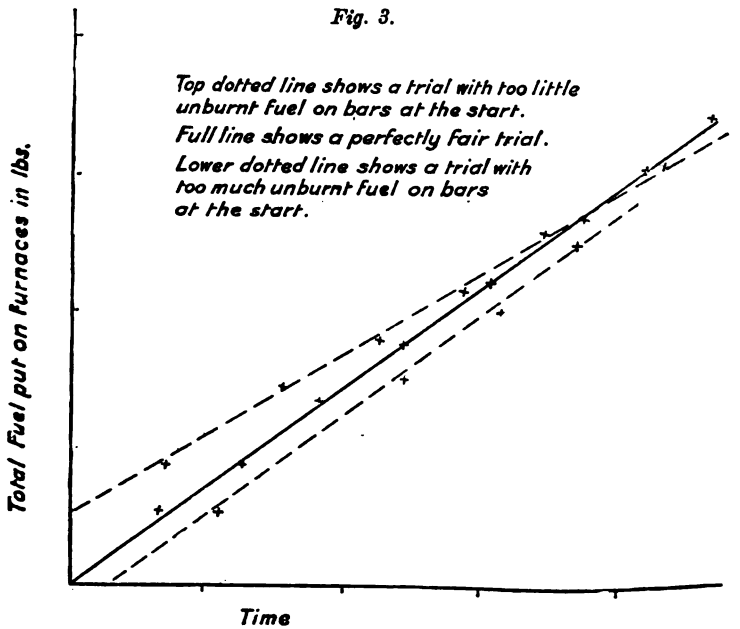
line of fuel consumption. As in the rate method, the coal used should be plotted on a time base; but it is advisable perhaps to plot the weight of each charge, not for the time when the first shovelful of that charge was thrown on to the fire, but when the first shovelful of the following charge was thrown on, the assumption being that the charge is completely burnt, not at the time when it is put on, but at the time when more coal is required to maintain the regular rate of evaporation. In a trial perfectly conducted in this manner the plotted coal line should pass through the origin as shown in the diagram (*Fig. 3*). It will fall above or below the origin

Fig. 3.


Top dotted line shows a trial with too little unburnt fuel on bars at the start.
Full line shows a perfectly fair trial.
Lower dotted line shows a trial with too much unburnt fuel on bars at the start.
Total Fuel put on Furnaces in lbs.
Time

according to whether too little or too much unburnt coal was on the grate at the beginning of the trial, and the amount is given by the intercept on the vertical.

C. *The third method*, applicable when the boiler can be run at approximately the normal rate for some time previous to the commencement of the trial, is as follows:—

(1) The boiler having been at work at full pressure long enough to heat the brickwork (if any) to the normal working temperature, the principal observer should order the fires to be cleaned, and note the time of giving the order. This order should be given as

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short a time before the commencement of the trial as will allow of the grates being cleaned, and the fires made up and burnt through before the starting time; half-an-hour to an hour will generally suffice, but of course the time required depends on the number of furnaces, the adhesiveness of the clinker, and the number of stokers available. The fires should be cleaned in some definite order, say from right to left, and should be at once made up with unweighed coal.

(2) The ashpits, the flues behind the bridges, and, in the case of travelling bars, the flues beyond the back-ends of the grates, should be cleaned out. It is true that the removal of all the hot clinker and burning fuel from the flues generally reduces the evaporation, owing partly to the removal of a considerable quantity of hot material, but principally to increased admission of cold air past the ends of the bars and round the doors below the back-ends of the grates. When merely comparative results are required the loss is of no consequence; but, if absolute economy is being tested, either some allowance must be made to the guarantor of the boiler, or the trial must be continued long enough to render this effect negligible.

(3) While the fires are burning through, the ashes, etc., should be removed from the stokehole floor, but they are not to be weighed.

(4) As soon as the fires have burnt clear and as low as is compatible with keeping up the steam-pressure, the principal observer should again note the time, and blow a whistle or ring a bell to notify the commencement of the trial to his assistants, who will immediately note the water-levels in the gauges and the steam-pressure. The principal observer himself should then take a rake or a specially made tool, level and gauge each fire in several places, and note the average thickness on each grate. If the fires be not more than 3 inches or 4 inches thick, the duration of the trial required to attain any required degree of accuracy may be halved by pushing the whole of the fire on to the back half of the grate before gauging the thickness. The weight of fuel in pounds on each grate may be taken as $A \times T \times 2{\cdot}5$ for slack, or as $A \times T \times 1{\cdot}7$ for large coal, where A is the area of the part of the grate covered by the fuel in square feet, T, the average thickness of the fuel in inches.

(5) About half-an-hour or an hour before the intended conclusion of the trial, according to the time occupied in preparation before the commencement, the principal observer should note the time, and then superintend, (*a*) the cleaning and making up of the fires in the same order in which they were cleaned before the trial ing of the ashpits (and in the case of moving

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bars, the flues beyond the ends of the bars). The ashes and clinkers removed from grates, ashpits and flues on this occasion must be weighed, but no ashes, clinker, or fuel that may accumulate on the bars, or in the ashpits and flues after the cleaning, must be withdrawn or taken account of. During this time the principal observer should carefully watch the fires to see that they are burning evenly through, and not becoming so thin as to form holes, through which air can flow, and so reduce the steam-pressure. It is not necessary that they should be exactly the same thickness as at the commencement of the trial, but they ought to be of the same quality, *i.e.*, as well burnt and without green coal.

(6) At the end of the allotted time the principal observer should again blow his whistle so that the water-feed, and if there be mechanical stokers, the coal-feed, may be stopped and the water and steam-gauges read by his assistants. He himself should again gauge the thickness of the fires as at the commencement of the trial, so that the weight of fuel on the grates may be calculated. If this exceed or fall short of the weight on the grates at starting, the excess or deficiency must be deducted from or added to the weight of fuel used during the run. (Strictly speaking the excess or deficiency should be multiplied by the fraction representing the non-combustible proportion of the fuel, and the product deducted from or added to the weight of dried fuel used, but this refinement is practically unnecessary, as the error introduced by neglecting it will in general be quite negligible.)

At the end of the trial it is not necessary and generally not advisable to attempt to bring the water in the boiler up to exactly the same level,[1] or the fires to exactly the same thickness, as at the beginning.

The things that should be brought to the same state at the beginning and end of the trial are:—(1) the quantity of heat stored in the brickwork; (2) the quantity of heat stored in the economiser; (3) the steam-pressure approximately; (4) the rate of evaporation per unit of time, since the height of the water in the gauge-glass is thereby materially affected, being always higher —often 1 inch higher—when the boiler is giving off its full supply of steam than when evaporation has nearly ceased.

In many classes of boilers the water-gauges can be read to within $\frac{1}{4}$ inch, but sometimes it is difficult to decide the level within $\frac{1}{2}$ inch. The possible algebraic sum of the errors at the

[1] See foot-note, p. 238.

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beginning and end of the trial may therefore be ½ inch to 1 inch. Hence, to obtain an accuracy of 1 per cent., the duration of the trial should be sufficient for the evaporation of a weight of water equal to 100 times the weight of a layer of water ½ inch to 1 inch in thickness, according to the mobility of the level in the gauge-glass. This will nearly always be less than the duration required to ensure an equal degree of accuracy in estimating the fuel-consumption.

No. 2.—Duration of Trial.

When the conditions mentioned in the last paragraph cannot be obtained, at least approximately, a long trial is necessary to insure accuracy, but when matters can be so arranged that the trial may be considered as a slice, so to speak, cut out of a period of uniform working, then the duration of the trial depends principally upon the magnitude of the error likely to be made in judging the condition and thickness of the fires at the beginning and end of the time, as compared with the weight of fuel burnt during the trial. This judgment should therefore be made by the principal observer. In most cases he will find it possible to measure the thickness of the fuel on the grate to within 1 inch. The weight of a layer of fuel 1 inch thick should therefore represent the maximum error in measuring the thickness of the fire, and this error may be in opposite senses at the beginning and end of the trial. If therefore A be the area in square feet of the part of the grate covered by the fuel when the measurement is made, and C the weight of a cubic foot of incandescent fuel which will vary between 30 lbs. for small slack and 20 lbs. for large coal, the total error should not exceed $C \times A \times {}_1{}^2_2 = \frac{C A}{6}$ lbs. Therefore if W be the number of pounds of fuel burnt per hour, the duration of trial which will reduce the total error to 1 per cent. of the total fuel burnt is $\frac{100\,C A}{6\,W}$ hours, and to n per cent. of the total fuel burnt $\frac{100\,C A}{6\,n W}$ hours. In making use of this formula, however, it is necessary to have some regard to the quality as well as the size of the fuel. When it contains much dirt or makes a pasty clinker, the bars, if not self-cleaning, have to be cleaned at short intervals by the firemen, and at each cleaning there is loss of heat and combustible matter. The duration of the trial and the times of cleaning should therefore be so arranged as to give this loss the same average value that

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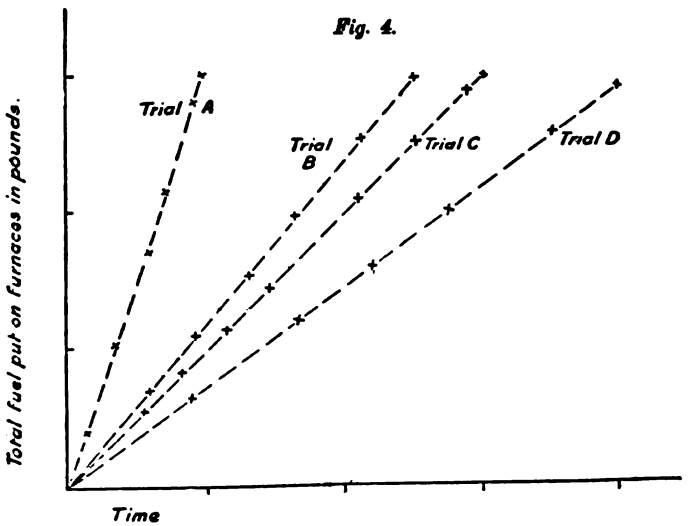
it would have if the trial were indefinitely prolonged. For instance, if the fuel were such as to make cleaning necessary every 4 hours, it would be unfair to make a 5 hours' trial; 8 hours would be the proper time; or, if it were not possible to have the trial longer than 5 hours, a more accurate result would be obtained by working for 4 hours only and cleaning the fire-grates only once.

In connection with the duration of boiler trials, it should be remembered that if one boiler burns more coal per square foot of grate area than another per unit of time the trial may be of proportionally shorter duration without increase of error. The only object of prolonging the trial is to reduce the importance of an error in judgment as to the condition of the fire at the

Fig. 4.



beginning and the end of the test. This error may be taken to represent a constant weight of say w lbs. of coal on a grate of given area for a trial of any length.

When burning W lbs. of coal per hour the coal burnt in N hours will be NW, and the fractional error will be $\frac{w}{W} \times \frac{1}{N}$. The second term of this fraction is the only one usually considered, hence the long trials, which are necessary with slow rates of combustion, are sometimes specified without reason in the case of trials under forced draught.

If, however, W is greatly increased the percentage error is not increased by reducing the duration of the trial. This is

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shown graphically in *Fig. 4*. In each of the four trials shown on this diagram at different rates of combustion the same weight of coal is burnt. Since in 1 hour in the one trial as much coal is burnt as in 4 hours in another, the percentage error is only the same in both cases, although the duration of the trial in the one case is 1 hour and in that of the other 4 hours.

No. 3.—Weighing the Fuel.

The fuel should be weighed on a platform weighing-machine, or on beam scales, or by a *calibrated* spring balance, in parcels of 20 lbs. to 200 lbs. according to the size of the boiler to be tested. It may be weighed before or during the progress of the trial.

In the first case each parcel should be stored in a sack, which should be sealed and should bear a numbered label. In the second case, two boxes or vessels of equal weight, and marked conspicuously No. 1 and No. 2, should be provided for holding the fuel upon the scales and carrying it to the stokehole floor.

Shortly before the trial commences, No. 1 box should be filled till it balances the weights in the scale, and at the moment the trial starts its contents should be tipped upon the stokehole floor. When the first lot is nearly finished, No. 2 box should be filled and its contents tipped out upon the floor as soon as the whole of the fuel from No. 1 box has been stoked, and so on, the boxes being used alternately. No. 1 box should not be brought back from the stokehole till No. 2 has been tipped. The tally should be kept in the following form:—

Trial of No. — Boiler at _____ Date _____

Time of emptying No. 1 Box on Stokehole Floor.	Time of emptying No. 2 Box on Stokehole Floor.	Time Interval. Minutes.	Remarks.
9.5	..	..	
..	9.15	10	
9.24	..	9	
..	9.36	12	

By keeping the tally in this form the observer cannot miss or add one box; he must, if an error is made, miss or add two, and if he do so, the mistake will be detected by the inequality in the intervals of time. Inequalities in the time intervals which occur when filling up the furnaces after cleaning the grates, or from any other cause, should be noted in the "remarks" column. The

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stokehole floor should be swept clean before the commencement of the trial, and any fuel lying on it at the end of the trial should be weighed and deducted from the quantity shown by the tally to have been weighed out.

When sacks are used instead of boxes the log-sheet can be kept in the following form:—

Trial of No. — Boiler at_____ Date_____

Number of Sack.	Time of emptying on Stokehole Floor.	Time Interval. Minutes.	Remarks.
1	9.6	...	
2	9.11	5	
3	9.16	4	
4	9.22	6	
5	9.28	4	

The sacks should be used in the order of the consecutive numbers upon the labels, and as each sack is emptied upon the stokehole floor, the label should be taken off, endorsed with the time and retained by the observer.

Where mechanical stokers are used they should be stopped just before the commencement of the trial and the hoppers filled with unweighed fuel. At the end of the trial they should again be stopped and the hopper filled up with weighed fuel.

If the rate of combustion be required more accurately than is given by the tally sheet, an observer should stay in the stokehole and keep count of the number of shovelfuls thrown on to each furnace, and the times of throwing on. The total weight of fuel used divided by the total number of shovelfuls fired will give the average weight of each shovelful, and thus allow a curve to be plotted with the weights of fuel burned as the ordinates and the time of firing as the abscissæ.

No. 4.—Sampling, Calorific Value and Analysis of Fuel.

When the fuel is coal, the sampling is a matter which requires great care, in order that the sample may be a good average of the coal actually used. The best way is to take half a shovelful from each sack or box weighed out and pile it in a heap where it will neither lose nor absorb moisture. Shortly before the conclusion of the trial the heap should be well turned over and the large lumps broken up; it should then be quartered, one quarter selected

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for further mixing and breaking, and the rest handed over to the stoker for firing. The selected portion should then be pounded, mixed, and quartered and so on until a weight of about 3 lbs. or 4 lbs. remains. This final sample should be at once placed in a wide-mouthed bottle, or other air-tight receptacle, which has been carefully dried beforehand, and corked and hermetically sealed. The whole operation should be carried out as quickly as possible to prevent loss of moisture by evaporation during the process of sampling. When in a fine state of division certain coals lose moisture very rapidly on exposure to the air.

The determination of the heat value of this sample can be most accurately determined by burning it with compressed oxygen in a bomb calorimeter; this instrument[1] is, however, difficult to use, and therefore it is recommended that the sample be sent to a chemist skilled in its use, who should also determine the percentages of carbon, hydrogen, nitrogen, sulphur, ash, etc., and moisture by analysis.

No. 5.—Measurement of the Feed.

It is desirable but seldom practicable actually to weigh the feed-water; some system of measurement must therefore be resorted to. The arrangement most generally applicable is that of two measuring-tanks marked No. 1 and No. 2, and a feed-tank connected to the feed-pump or injector as sketched in *Fig. 5.* If necessary the feed-tank may be dispensed with and the measuring-tanks coupled direct to the feed-pump. The fall (a b) to be arranged for in the water-level in the measuring tanks depends upon the exactness with which the upper and lower levels can be observed and the degree of accuracy required in the observations. With a float or glass gauge as shown in the diagram the levels can generally be read to about $\frac{1}{16}$ inch. When the upper level is regulated by an overflow-pipe an error of $\frac{1}{8}$ inch may arise. Assuming the error in the top and bottom readings to be in opposite senses, the total error would be $\frac{1}{8}$ inch in the first cases and $\frac{3}{16}$ inch ($\frac{1}{8} + \frac{1}{16}$) in the last. In order, therefore, that this total error may be 1 per cent. of the quantity measured, the fall in the water-level must be about 12 inches in the first two cases and 19 inches in the last. Generally it will be possible to obtain a greater fall and so reduce the maximum possible error to $\frac{1}{2}$ per

[1] A full description of this calorimeter will be found in Carpenter's "Experimental Engineering," 1900, p. 421.

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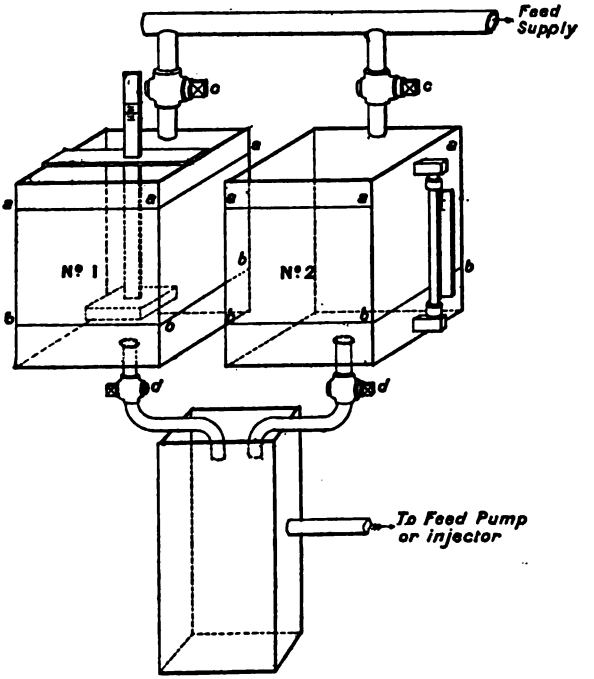
cent. or less, and this should, if possible, be arranged for. The volume of the tanks should be such that each may hold about 7 minutes' (never less than 5 minutes') supply, so that the observer may have ample time to manipulate the cocks, take the temperature of the water, and book the figures. When very large quantities of water have to be dealt with a pair of measuring-tanks coupled at the bottom by a pipe of large bore may replace each of the measuring-tanks shown in *Fig. 5*. The supply-pipe and plug cocks *c c* must be of sufficient bore to fill each tank in about half

Fig. 5.



the time allowed for discharge, so as to allow time for regulating the top-level. When a float is used the pipe *c* must not discharge on top of it, and the vertical rod must be as light as possible in order that it may not be top-heavy. The mouth of the pipe *c* should be easily visible when the water-level is at *b b*, so that any leakage past the cock may be detected. It is best to keep it always above water. If valves be used instead of cocks, as shown at *d*, they ought to have swivelling-elbows, so that if they leak, as they

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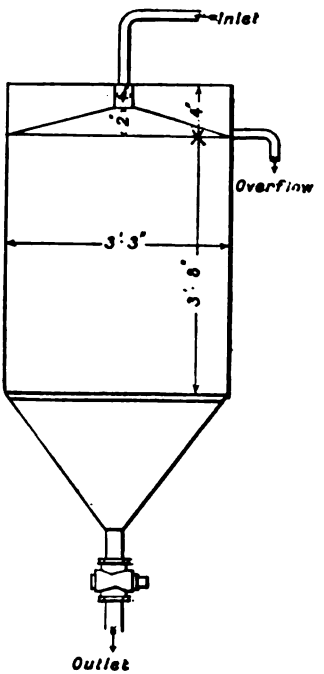
generally do, the leakage may be diverted from the tank. Valves must not be used in place of the cocks *d d* when the measuring-tanks are coupled directly to the feed-pump without the interposition of a feed-tank, as they cannot be relied on to keep tight; a small piece of waste or wood may prevent them closing. The lowest water-level *b b* should in any case be some inches from the bottom of the tank so as to keep the discharge pipes full and under a moderate head of water in order to hasten the discharge. When there is no feed-tank it will generally be found necessary to have 6 inches to 9 inches of water in the bottom of the measuring-tank to prevent agitation of the surface by the intermittent suction of the pump. The extent of the water-surface in the feed-tank is not a matter of indifference. It should be as small as possible, so that variations in its level may not cause any material difference between the quantity of water discharged from the measuring-tanks and the quantity fed into the boiler. If the surface cannot be made small its level should be kept steady. A feed-tank about one-fourth the capacity of one of the measuring-tanks will generally suffice.

Fig. 6.



When measuring-tanks can be obtained with conical or pyramidal tops and bottoms (*Fig. 6*) they can be filled to overflowing, and if there be a feed-tank they can be completely emptied, but such conveniences are not often available.

Calibration of Measuring-Tanks.—This ought to be done by *weighing* the contents of each tank between the working levels and if possible at the working temperature of the feed. If the tanks themselves cannot be put on the scales, the contents should be measured in a can with a narrow neck, or with an overflow hole in the side about 25 inches from the bottom. The contents of this can should be ascertained by weighing.

The capacities of the tanks may be gauged either by pouring

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water into them from the can, or by running water out of them into the can. The former method is probably the more convenient with a narrow-necked can, the latter with a tall open-topped can. Another plan is to place a vessel of any shape upon the scales, to run the water from the measuring-tank into buckets, carry it to the scales, pour it into the vessel and weigh it. The scales used for weighing the coal may be used, and a barrel or tank which holds 200 lbs. or 250 lbs. of water.

Method of using the Measuring-tanks :—

(1) Some little time before the commencement of the trial the observer in charge of the feed-measurement should fill up No. 1 measuring-tank to the top level, feeding the boiler in the meantime through the No. 2 measuring tank and the feed-tank. The feed should if possible be kept on at the rate intended for the trial until the principal observer is nearly ready to sound his whistle as a signal to begin the observations.[1]

(2) As the time for starting approaches, the feed-pump should be stopped, the cock *d* in No. 2 tank shut, and the water-level in the feed-tank marked and recorded. After the whistle has sounded the feed-pump may be again started as soon as convenient.

(3) The cock *d* on No. 1 measuring-tank and the cock *c* for feeding No. 2 are then to be opened. While No. 1 is being emptied No. 2 should be filled and the water-level adjusted to *a a*. As soon as the water-level in No. 1 has fallen to *b b* its cock *d* should be shut and the cock *d* on No. 2 opened. The cock *c* for No. 1 should then be opened and No. 1 filled up while No. 2 is being emptied, and so on.

(4) The log of the feed measurements can best be kept by entering on it the time of starting each tank, that is, the times of opening the cocks *d* as shown below :—

Time of commencing Trial_____ Date_____

Time when Tanks were started.				Temperature.	Time Interval. Minutes.	Remarks.
No. I.		No. II.				
Hour.	Mins.	Hour.	Mins.	°F.		
9	1	..	..	58	..	
..	..	9	8	58	7	
9	16	..	..	59	8	
..	..	9	22	59	6	

[1] It is necessary to keep on the feed if there is an economiser to prevent it getting unfairly hot.

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(5) A minute or two before the end of the trial the feed-pump should be stopped, and whichever cock *d* happens to be open (say that of No. 2 tank) should be shut, and the height of the water in the feed-tank noted.

The weight of water passed through the measuring-tanks can be obtained from the log-sheet as follows:—

	Lbs.
No. 1 emptied *m* times	
„ 2 „ *n* „	
„ 2, say, $\frac{s}{t}$ parts used	
Add or deduct for difference of level in feed-tank . .	
Total measured	

This total, corrected for leakage from the feed-pump gland, is the feed to the economiser or boiler. If there be leakage from the economiser safety-valve or other fittings, it must be caught and measured, and its amount deducted, the remainder being the feed to the boiler.

If the water-level in the boiler be the same at the beginning and end of the trial, the quantity of water evaporated (neglecting priming) will be equal to the feed; but if not, a weight equivalent to the difference of level in the gauge, calculated as explained in the note at the foot of page 238, must be added or deducted according as the final level is below or above the level at starting.

No. 6.—Sampling the Ashes and Determination of Combustible Matter therein.

The whole of the ashes and clinker collected, as previously explained, should, after drying and weighing, be thrown into a heap and well turned over to mix them thoroughly. The heap should then be quartered and the large pieces broken up, and this process of quartering and breaking up the large pieces should be continued upon the lines described for sampling the coal, until 3 lbs. or 4 lbs. are left. This sample should then be placed in an air-tight dried vessel and sent to an expert chemist for determination of the percentage of combustible matter in it.

It should be pointed out, however, that if a chemical analysis of the fuel has been made, it is possible to determine the quantity of combustible matter mixed with the ashes by simply deducting the weight of ash corresponding to the fuel fired as given by the fuel analysis from the weight of the material drawn from the furnaces and ashpits.

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In consequence of the great difficulty of obtaining a true average sample of the ash this second method is generally the more accurate. In estimating the weight of the ash and clinker it must not be forgotten that some portion is always carried over the bridge by the draught. When the draught is strong, particularly when sprinkling stokers are in use, this proportion may be considerable, insomuch that the total weight of material drawn from the furnaces and ashpits may weigh even less than the total ash contained in the fuel as determined from the chemical analysis.

No. 7.—Measurement of Pressure or Vacuum in the Ashpit, Chimney Draught, etc.

The usual U-gauge is too well known to engineers to need any description, but it may be pointed out that when used with the two limbs vertical the readings are usually so small as to be difficult to observe accurately. The readings may be considerably magnified, and the proportion of the meniscus error much reduced, by inclining the gauge.

Mr. Macfarlane Gray has designed[1] a very convenient gauge, in which the readings are magnified by the use of two liquids of different specific gravities combined with a special form of U-tube.

No. 8.—Measurement of the Water formed by Condensation in Steam-Pipes.

An accurate measurement of the steam condensed in the steam-pipes is generally impossible, as a proportion of it, in many cases a very large proportion, is carried forward to the engine. In most cases drain-pipes are arranged only to carry away water formed while there is no current in the pipes, and are almost useless when the engine is running, as the globules of water are then moving with sufficient velocity to jump the openings into them. Even where special arrangements of separation and well-pipes exist it is very doubtful if all the water is extracted from the steam.

Such water as is discharged should be caught and measured, and as it generally arrives at the outlet at a temperature above 212°, a considerable portion may escape as steam unless special precautions are taken. Accuracy can only be obtained by passing the discharge through a worm immersed in cold water or some similar device,

[1] Minutes of Proceedings Inst. C.E., vol. cxlvii. p. 235. An account is also given of a convenient method of shielding the gauges from local currents in the ashpits, etc.

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but a near approach to accuracy can be obtained by using a deep vessel, so that the evaporation-surface shall be as small as possible, arranging the discharge-pipe to deliver under the water (a known weight of water sufficient to cover the end of the pipe should be put into the vessel) and using a little oil to make an oil-film, and thus diminish evaporation.

No. 9.—Measurement of the Steam Passing through the Engine.

The measurement of the steam passing through the engine can be effected in two ways:—

1. By deducting from the measured boiler-feed:
   (*a*) The steam condensed in the steam-pipes.
   (*b*) The steam used for other purposes, such as boiler-feed, pumps, etc.
   (*c*) The leakage of steam from the steam-pipe joints.
2. By condensing the exhaust steam and weighing the resulting water.

This latter method is generally the more accurate, but, unfortunately, when an engine is tested *in situ* this method can only be adopted if the engine is fitted with a surface condenser. In this case it is only necessary to measure the rate of flow of water from the hot-well, provided, in the case of open engines, the leakage from the piston glands, etc., is inconsiderable. In enclosed engines the piston-rod leakage can be collected and measured.

In works where engines are systematically tested, the surface condenser method of measuring the steam consumption of the engine is usually adopted, and the water flowing through the condenser, whether condensed at atmospheric pressure or under a vacuum, is led into a tank placed on a weighbridge. An electric contact is fitted to the steelyard, so that an electric bell rings the instant the balance is obtained. A uniform flow having been established, and it being desired to begin to measure this rate of flow into the tank, the first step is slightly to overbalance the steelyard, so that in a few seconds, owing to the flow of water, the balance will be again established. The time at which the bell rings is recorded. The steelyard is now overbalanced, say 100 lbs. Obviously, as soon as another 100 lbs. of water have flowed into the tank the bell will ring again, and the time at which this occurs is recorded. From data thus obtained the rate of flow can be readily deduced. In practice several 100 lbs. intervals are observed, to obtain greater accuracy, and to ascertain that the rate of flow is uniform. When testing large engines the 100 lbs. may be increased to 200 lbs., 300 lbs., or even more, so that the time intervals shall not be much

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less than 2 minutes. In general, observations lasting about half an hour will give results within ¼ per cent. Similar sets of observations can be taken at intervals, during a trial which may last 6 hours or more, in order to test endurance and for other purposes. In this way any change in the working condition of the engine can be detected.

To approximate to the above method with extempore apparatus a barrel can be placed on a portable weighbridge, and the time required for say 100 lbs. to flow into it observed, preferably by means of a stop-watch. The calibration can be best effected in this case by first placing the barrel together with 100 lbs. on the weighbridge and balancing. Any error in the weighing machine is thus eliminated.

Such arrangements are only possible, however, when testing comparatively small engines, as the quantity of water to be dealt with in large engines would be unmanageable. In this latter case a large tank should be used which has been previously calibrated up to a mark by weighing water into it. The tank should be fitted with a valve to empty it. If two tanks are available the water can be allowed to flow first into one, and then into the other, and thus continuous measurement of the rate of flow can be made; this is obviously not possible with only one tank. The method of calibrating the tanks in this case is identical with that described for obtaining the feed measurement of the boiler.

A fairly good result can also be obtained by placing a water-meter in the circuit of the pump suction. The meter should, however, be calibrated with water of the temperature of the feed, both before and after the test and when passing about the same quantity per hour as during the trial.

No. 10.—Measurement of Temperature.

(*a*) *General Remarks.*

In general, the thermometers used should be chemical thermometers, made of hard glass, and it is of importance that they should be checked from time to time, since most thermometers, especially if used for measuring high temperatures, change their zero points gradually. It is not necessary to have thermometers constantly checked at a public laboratory; it will be sufficient to test them in melting ice and in steam at atmospheric pressure. For most engineering purposes the graduation of an ordinary thermometer is sufficiently accurate, provided that any error in the zero point is added to or subtracted from the readings.

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The only engineering measurements of temperature which may require exceptional accuracy are those needed in the determination of the rise of temperature in the discharged water from the condenser, which, under some circumstances, may be very small; in this case the thermometers used must be very carefully compared, or, better still, a differential method should be adopted.

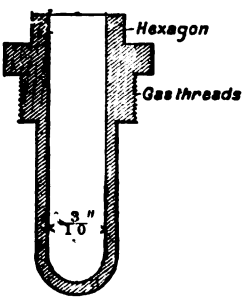
It is not advisable to use expensive thermometers, owing to the great risk of breakage, but to use moderately good thermometers, comparing them before and after the test with a standard instrument. It is important, however, to use sensitive thermometers when measuring varying temperatures, otherwise the lag in the movement of the mercury may cause serious errors.

(*b*) *Air- and Water-Temperatures.*

Air-Temperature.—This calls for no special remarks beyond those in the general hints given above.

Water-Temperature.—This temperature, unless the supply is taken from the mains or other source at a steady temperature, should be measured every time a tank or measuring vessel is filled, care being taken that the water is thoroughly mixed and that the thermometer is read while inserted to a proper depth. If it is not possible to read the thermometer under these conditions a small quantity of water should be drawn off or dipped out, and the temperature of this taken. Even with an ordinary thermometer it is not accurate enough to read the thermometer after it has been taken out of the water; the reading must be taken while the instrument is in the cup or tank.

Fig. 7.



In some cases, especially when the feed-water is measured through a meter, or is passed under pressure through a feed-heater, and also in the case of water returned to the boiler from jackets, re-heater, etc., the temperature of the water cannot be directly measured. In this case it is necessary to drill a hole in the pipe and to screw in a cup into which the thermometer is inserted.

The cup should have walls as thin as possible—a good form being shown in the sketch (*Fig. 7*); it should be made of steel and filled with mercury into which the bulb of the thermometer is dipped.

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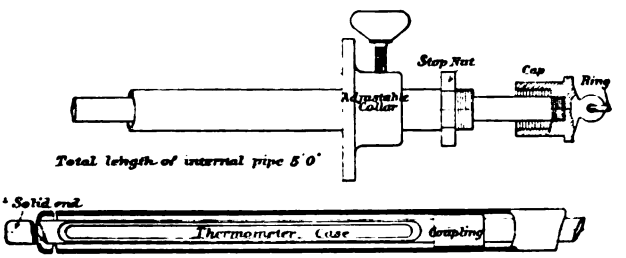
(c) *Flue-Temperatures.*

The flue-temperature should be taken as close as possible to the exit from the boiler flue. It is in many cases difficult to obtain the average temperature, and it is therefore advisable to have two or more holes cut in the brickwork, and to ascertain by trial the best position for the thermometer.

Flue-temperatures, below 600° F., can be measured with considerable accuracy by means of mercurial thermometers; but care must be taken to select thermometers made of Jena or other very hard glass, with the space above the mercury filled with nitrogen, or other gas which does not affect mercury. Unfortunately the most accurate mercurial thermometers are those of small diameter, and, if made long enough to reach the middle of a deep flue, they are extremely delicate and liable to be easily broken. Short thermometers may, however, be used by enclosing them in iron cases which themselves fit into larger cases pushed through holes

Fig. 8.



in the flue-walls or roofs (*Fig. 8*). The hot iron round the bulb of the thermometer retains its heat long enough to prevent any change in the position of the mercury while the inner tube is withdrawn and the thermometer read, and the outer casing protects the glass from smoke and soot, which would otherwise render the markings illegible.

Thermometers for taking flue temperatures should not be too sensitive, as it is not desirable that they should be affected by every opening of the furnace doors.

The various forms of pyrometers which work by the expansion of two different metals, or by the alteration of the pressure of mercury in their bulbs, etc., are most of them uncertain and cannot be relied upon to record accurately for any length of time.

The most accurate and convenient method of obtaining flue-temperatures is the electrical one; either the resistance of a plati-

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num spiral is observed, or the electromotive force generated at a thermo-electric junction is measured, and from these observations the temperature can be deduced. Instruments of both classes can be obtained, the resistance instrument being made in a form suitable for using in an ordinary boiler-flue; the thermo-electric couple requires a reflecting galvanometer. The description of these instruments would be out of place here, but they have been given[1] in the Proceedings of the Institution.

(*d*) *Steam-Temperatures.*

These can be measured either by plunging a mercurial thermometer into a mercury cup screwed into the steam-pipe, or by an electrical method.

Mercury Cup.—If this method is used, great care must be taken to avoid the effects of conduction and radiation, for if the mercury cup is provided with a large solid head, the effects of the radiation from this may render the readings of the thermometer quite unreliable. The mercury cup must also be of considerable length so as to project well into the pipe, and the stem of the thermometer should be immersed far enough to cover most of the mercury column.

Hard glass thermometers should be used for taking the temperature of high-pressure or superheated steam, and care must be taken to correct for change of zero.

Electrical Methods.—Electrical thermometers, based either on the resistance or the thermo-electric couple method, can be used for taking steam temperatures; special instruments are now made for this purpose.

No. 11.—Collection and Analysis of Gases.[2]

In the case of locomotive, marine and other boilers without external flues, there is no difficulty in deciding whence the gases for analysis should be drawn, as their composition is not changed by air-leakages; but in the case of boilers set in brickwork some judgment is required in order to secure fair average samples suitable for the purpose required.

When the object is to investigate the quantity of air admitted to the furnace, the sample should be drawn, if possible, before the

[1] "On the Measurement of High Temperatures." By Professor W. C. Roberts-Austen, C.B., F.R.S. Vol. cx., p. 152.

[2] This matter will be dealt with more fully in a special Supplementary Report.

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gases enter any of the brickwork flues, so that the sample may contain only the proportion of air which has passed through the furnaces. In Lancashire or Cornish boilers, for instance, the gas should in this case be drawn from the downtake at the end of the internal flues.

If, however, the object be to ascertain the quantity of heat carried away from the boiler, the sample (in the case of boilers of the two classes last mentioned) should be taken at the exit from the external brickwork flues into the economiser or chimney, as the case may be, where the temperature of the gases is also measured. In either case care must be taken that the mouth of the aspirating tube is placed in the full current of the gases, and in a place unaffected by local air leaks through cracks in the brickwork, through spaces between the boiler plates and the bricks or tiles supposed to be in contact with them, or through ill-fitting damper frames or other openings into the external flues.

When boilers are fired by mechanical stokers, the gas samples may be drawn directly into an analysing apparatus, but when the firing is by hand continuous collection is necessary to ensure correct results.

When all the gas aspirated passes into the collecting-vessel the volume of the aspirating-tube must be very small compared with the volume of the vessel into which the gas is drawn, otherwise the sample collected will contain little besides the gas lying in the tube when the collection was begun.

If the gas cannot be analysed on the spot it must be collected over mercury. Indeed, it is better always to collect over mercury, although it is probable that when the analyses can be performed at once, collection over distilled water saturated with salt, acidulated and tinted with methyl-orange as described below, or with furnace-gas, yields results sufficiently accurate for practical purposes.

When the collection is made over mercury the collecting-vessel must necessarily be small. Therefore, if it be connected directly to the aspirating-tube, the tube must be of very small bore, and is then easily choked with flue-dust, and troublesome to work with. Hence it is generally best to use a tube of about $\frac{3}{16}$ inch or $\frac{1}{4}$ inch bore, and to aspirate a comparatively large volume of gas, shunting only a small portion of the main current into the mercury vessel. Where there is a water-supply near the boiler the main current can easily be produced by an ordinary Bunsen water-pump, but where there is no supply the following arrangement (*Fig. 9*) may be convenient, as it is portable, and requires no apparatus

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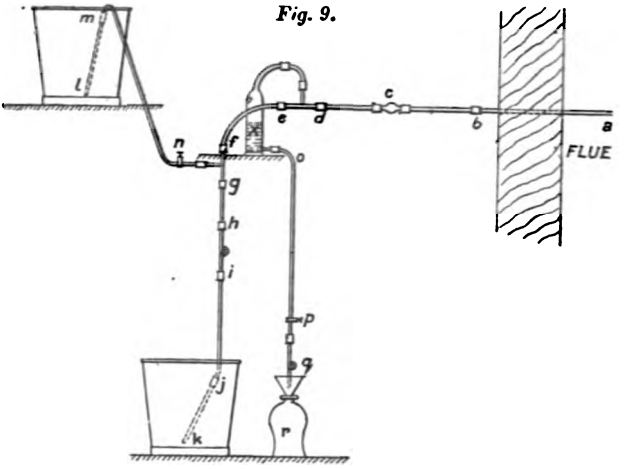
beyond wo buckets and a little glass and india-rubber tubing, which should be strong pressure-tubing of small bore.

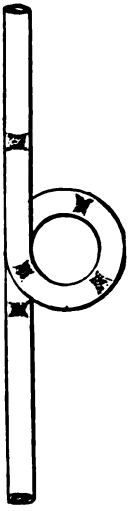
Fig. 9.



a b is the metal tube entering the flue.

b c d, an india-rubber tube in which is a small glass bulb (*c*) filled with cotton wool to arrest flue-dust.

Fig. 10.



d e, a glass T-piece by which the shunt current is diverted into the mercury bottle (*x*).

f g, a second glass T-piece by which water from the upper bucket enters the tube *f g*.

h i, a glass tube bent to the shape shown in *Fig. 10*.

i j, a short piece of india-rubber tube, and

j k, a piece of glass tube resting on the bottom of the lower bucket, with its open end under water.

l m is a similar length of glass tube resting on the bottom of the upper bucket, and connected to the T-piece *f g*, by the india-rubber tube *m n*, carrying a pinchcock *n*, to regulate the water-supply. By properly adjusting this cock a continuous stream of small globules of water may be made to flow round the loop in the glass pipe *h i*, as shown in *Fig. 10*, carrying with them volumes of gas considerably greater than their own volumes. In this way a bucketful of water can be made to aspirate five or six times its own volume of gas, and the process can be continued for any length of time by putting back the water into the top bucket from the bottom one. The T-piece *d e*

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may be connected to a mercury bottle, of the shape shown in *Fig. 9*, to a Stead aspirator, a Bunte burette, or any other suitable vessel.

If it be desired to regulate the flow of the mercury at any desired rate, the outlet pipe may be provided with a stop-cock *p*, and a glass tube *q*, bent like the water-tube *h i*. By regulating the stop-cock, the loop in the glass tube may be gradually filled till it runs over into the jar *r*. By weighing, say, ten discharges, the weight of one discharge may be ascertained, and the cock *p* set to discharge this weight in any desired number of seconds, and thus any desired weight can be discharged from the collecting vessel in any desired time. In order that the discharge may remain fairly constant, the height *o p* must be three or four times as great as the height through which the surface of the mercury is required to descend.

With all the methods of collecting furnace gases adopted up to the present time it happens only too often that the samples collected are most probably not fair samples of the gases passing away from the boiler. As a result of experience in this matter, gained during the earlier naval boiler trials, the Committee on Water-Tube Boilers, on the suggestion of Mr. C. J. Wilson, are now adopting the following plan :—

A large pipe, about 1½ inch in diameter, with holes of considerable size in it, is inserted into the chimney, and is long enough to extend right across the chimney. At the outer end of this pipe a small electrically-driven fan is placed, which causes a current through the whole pipe at least equal in velocity to that of the current of gases as they pass into the chimney. This pipe is simply allowed to blow out into the open air, but an inner pipe placed within it will be used to take a sample of the gases from it. This plan has not been actually used up to the present in any of the trials, but will be adopted in the next series of trials made by the Admiralty Boiler Committee.

It is often necessary and advisable to carry out the analysis of the gases at once. The most convenient apparatus for this purpose is the Orsat apparatus, as it requires no supply of pure water and no bottles of chemicals.

A portable form of this instrument is shown in *Fig. 11*. L is a eudiometer, which is encased in a glass tube; this tube should be filled with water to form a jacket, and thus ensure a uniform temperature for all the gas measurements. F, G and H are flasks containing solutions of alkaline pyrogallate, cuprous chloride, and caustic soda, for the absorption of oxygen, carbonic oxide, and carbonic acid respectively.

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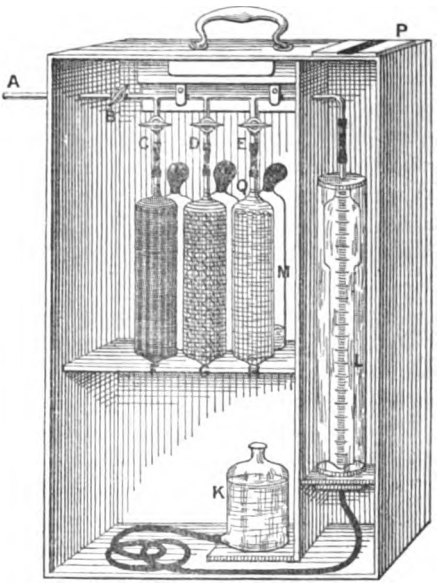
These reagent flasks contain a number of glass tubes packed together and open at the ends; by this means a large surface of reagent is exposed to the gas, as it is driven over into the flask. The duplicate flasks, as for example M, which are fitted with small rubber bags in place of stoppers, are provided for the reception of the reagents as they are expelled from those flasks with which each duplicate flask is respectively connected. K is an aspirator, and at B is a three-way cock making a straight connection, and also a connection with the atmosphere.

The method of using this instrument is as follows:—

Fig. 11.



ORSAT APPARATUS FOR GAS ANALYSIS.

The bottle containing the sample of gas is connected at A, means being provided for allowing water to enter it as the gases are withdrawn. All the other cocks being closed, B is opened to the atmosphere, and by raising the aspirator to the platform P, the eudiometer and the capillary tube are filled with the liquid contained in the aspirator K. The cock B is now turned so as to make a through connection, the aspirator is lowered, and the cocks on the sample bottle are opened until 100 cubic centimetres of gas are drawn in. When the measurement is being taken, the [illegible]he liquid in the aspirator and eudiometer must

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be the same. As soon as the sample is obtained the cock B is closed. It will be sufficient to explain briefly how the amount of carbonic acid in the sample is determined, as exactly the same operations are gone through in obtaining the amount of oxygen, etc. The stop-cock E is opened, and by raising the aspirator the gas is driven out of the eudiometer into the reagent flask H, containing the caustic soda. On drawing back the gas, the cock E is closed as soon as the reagent in H rises to its original level Q. It will be necessary to repeat this operation of driving the gas into H and drawing it back into the eudiometer several times, observing each time the decrease in volume of the gas; when no further decrease in volume is noted, all the carbonic acid will have been absorbed, and the total decrease gives the percentage of CO_2 present in the sample.

As it is important to know whether the temperature of the liquid in the aspirating bottle changes during the experiment, it is desirable to have a thermometer in this bottle.

The correction for change of temperature in the water, and therefore in the gas, is easily made, because the measuring tube is divided into 500 parts, each containing 0·2 cubic centimetre, and the increase in the volume of the gas for an increase of 1° F. in temperature is $\frac{1}{461 + t}$ part of its volume at the temperature t. Since t is generally between 50° and 70°, the increase in volume is roughly about $\frac{1}{500}$th part for each degree rise in temperature.

Thus if during the analysis the temperature of the water in the levelling bottle has risen or fallen 1° F., 0·2 cubic centimetre must be subtracted from or added to the readings taken after the rise or fall of temperature has taken place.

An analysis cannot be made in much less than half an hour, and has often to be made in most unsuitable places, so that changes of 1° or 2° in the temperature of the apparatus often occur, and ought to be allowed for in calculating the results.

When using the "Orsat" apparatus, one of the causes of error in the observations is the possibility of small quantities of alkali getting into the horizontal tube through which the gas passes to the eudiometer or into the liquid used in the eudiometer. In order to overcome this the eudiometer and bottle from which it is filled should be charged with a solution of common salt in water—about 20 per cent. This is made acid by the addition of a few drops of hydrochloric or sulphuric acid, and is then coloured pink with methyl orange. This liquid does not dissolve carbonic acid to any appreciable extent, and is very convenient

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to work with; experience shows that the salt does not give any trouble by crystallising in the tubes or cocks. As long as the liquid remains pink it is safe for use, since when alkaline it would turn yellow. After a determination has been made, if there be any suspicion that some of the alkali has got into the upper tube, this latter can be washed out by allowing some of the pink liquid to flow through the eudiometer and escape by the three-way cock; a few drops only are needed. When the escaping liquid is observed to be pink, the upper tube is then free from alkali. A small quantity of this washing liquid may probably pass into the vertical capillary tubes leading to the absorption vessels. This can be sucked into the absorption liquid without injury, as both absorbers are strongly alkaline, and the liquid is but feebly acid. Thus washed out, the apparatus is ready for another determination.

With this apparatus it is not possible to determine with any degree of accuracy the carbonic oxide present in the gases, because it is seldom present in such quantity as to make its determination trustworthy. The amount of carbonic acid gas and oxygen present can be determined to within 0·5 per cent., and if it is found when these two constituents are entirely removed that the residual nitrogen is 81 or 82 per cent. of the whole, then it may be conjectured that carbonic oxide is present. It should be remembered that the percentage of nitrogen will increase as the percentage of carbonic acid increases, since the hydrogen in the fuel appertaining to the carbon which produced the carbonic acid has removed oxygen, leaving its equivalent nitrogen behind.

If it is suspected from the "Orsat" tests that carbonic oxide is present, then samples of the gases should be submitted to a chemist skilled in gas analysis to determine the proportion present.

No. 10.—Indicating Steam-Engines.

It is proposed to refer only to certain points in indicating steam-engines which require special attention at the time a trial is being made. A full description of the use of the indicator and of the various kinds of indicators in practical use will be found in the various text-books on the steam-engine.

Indicator diagrams are used in an engine economy trial to obtain the mean pressures in the various cylinders, and for this purpose there is greater need of accuracy than when the diagrams are used merely to find out the point of cut-off of the steam, or the point at which compression commences, or any of the other various uses to which such diagrams are put.

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It is essential that the pressure in the indicator cylinder should be accurately equal, at all points of the stroke, to that in the engine cylinder, and to ensure this the connecting pipes must be of large diameter, short, and if possible, straight—at any rate, with very easy bends. The indicators, moreover, should, if possible, be placed upright, so that water may not lodge in them or in the pipes leading to them. In the case of double-acting engines, a separate indicator should be used for each end of the cylinder. It is further necessary, before each diagram is taken, to allow the steam to blow freely through, to clear out as much as possible any water which may have collected in the pipes, etc.

The motion of the drum carrying the card must be an exact reduced representation of the motion of the engine piston; slight errors in this respect may cause considerable errors in the mean pressure, particularly when the steam is cut off early in the stroke. Special attention therefore should be paid to the design and workmanship of the reducing motion.

The effect of inertia must be guarded against, especially in the case of high-speed engines, and also care should be taken to strain the spring inside the drum sufficiently to prevent any backlash, and to correct as far as possible for the inertia of the drum. The higher the speed of the engine, the greater should be the strain on this spring.[1] The indicator cord should be as short as possible, and should be well stretched before use. The indicators should be taken to pieces before the trial and carefully examined at the joints, and any slack taken up. The diagrams should be taken at frequent intervals, depending on the type of engine under test, and the possible variations in its load, and to ensure that all the diagrams are taken practically at the same instant there should be one observer to each cylinder; the pencil should be applied lightly for about 20 seconds to each diagram.

The indicator springs should be tested either before or after the trial, and it is of extreme importance that they should be tested under steam, that is to say, at the temperature at which they have to work. A comparison made with cold springs against a mercurial column is, however, better than no test at all. Unfortunately it is only at a few places that an apparatus is available, by means of which indicator springs can be tested hot.[2]

The diagrams are most accurately and rapidly measured by means of an Amsler (or similar) planimeter.

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxiii. p. 74.

[2] The National Laboratory at Bushey will be provided with such apparatus.

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APPENDIX II.

NOTES ON FILLING IN THE FORMS WITH THE RECORDS OF TRIALS, AND THE NATURE OF THE INFORMATION WHICH SHOULD BE GIVEN.

It appeared to the Committee to be desirable to explain briefly how the Forms they have drawn up should be filled in, and what kind of information should be given upon the Forms. They have therefore prepared the following notes:—

BOILER. SHEET I.

Reference Number. Line 1.—In describing a boiler, it should be treated as a machine for transmitting heat rather than as a structure for maintaining pressure. If it is of a well-known type, a mention of the type, of the dimensions of the shell, furnaces and tubes, and the course taken by the gases will generally suffice. If, on the other hand, the shape or arrangement be unusual, all the peculiarities should be carefully and minutely described. Descriptions of riveted joints, stays, safety-valves, and other particulars affecting the strength and safety of the boiler are not generally required. A drawing of the boiler and its setting and flues is a useful addition to the report of the trial.

The following example will serve as an illustration:—Lancashire type, ordinary form, length of shell 30 feet, diameter of shell 8 feet 6 inches; two internal flues each 3 feet 5½ inches in diameter, except at the front end of the first ring, where the diameter is reduced to 3 feet 2½ inches, and at the back end of the last ring but one, and at the last ring, where the diameter is 3 feet. Each flue has three Galloway tubes; the fire-grates are 5 feet 4 inches in length, with 12 inches of dead-plate in the front; the boiler is supplemented with a Green economiser. The brickwork about the boiler and economiser was in very good

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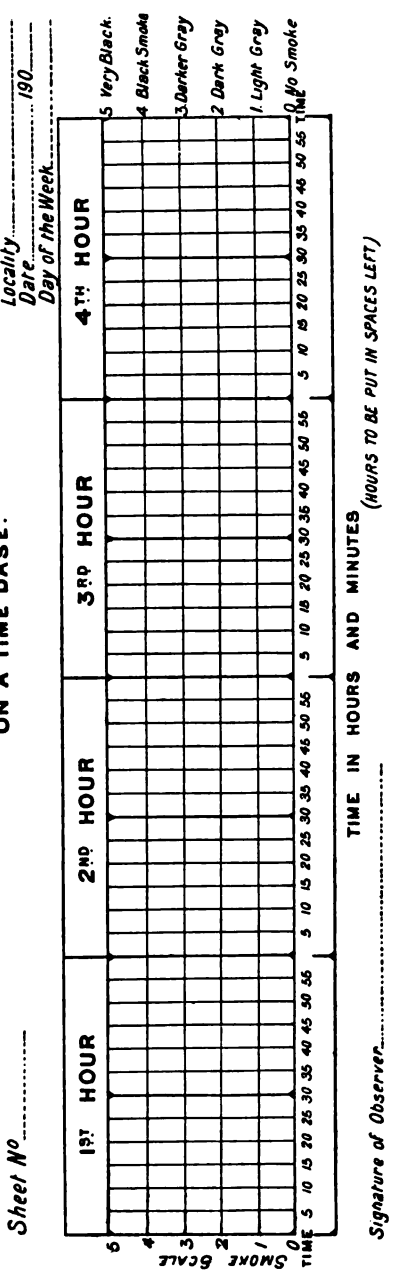
condition. The boiler and flues were thoroughly cleaned out four days before the trial.

Line 2.—If the method be one of those suggested on pages 237 to 244 in Appendix I., it will be sufficient to say so, and to state briefly which one of them. If, however, some other method has been adopted, it should be described accurately and in detail.

Line 3.—It should be stated whether the boiler was fired by hand or mechanically. If by hand, the size, weight, and frequency of the charges should be given approximately, and also some notes as to the degree of skill and intelligence displayed by the fireman. If mechanical "stokers" are used, the name of the "stoker" should be stated, and also whether the "stoker" was a sprinkler or a coker, unless the information has already been given under reference No. 1. In this case it is desirable, if possible, to give particulars of the power needed to work

Fig. 12.

PLOTTED DIAGRAM OF DEGREES OF INTENSITY OF SMOKE ON A TIME BASE.



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the stoker and how supplied. The general thickness and condition of the fires should be described, and the average thickness throughout the trial given, and anything in the methods of firing which would be likely to affect the rate of evaporation should be stated, and also how often and when the fires were cleaned.

Line 4.—If any system of forced or induced draught is used it should be carefully explained, and the positions and any peculiarities of the draught gauges described; data as to the power needed or steam used should be supplied if possible.

Lines 5–11.—The data given on these lines should be obtained with accuracy from actual measurements made at the time, or from the working drawings used in the construction of the boilers. In determining the amount of heating surface, all surfaces which are directly exposed to the gases leaving the fire-grate should be reckoned as heating surfaces. Thus in a Lancashire boiler the parts of the internal flues below the fire-grates are not to be considered as heating surface, but the bottoms of the internal flues beyond the bridges are to be so counted, although they may be covered with flue dust, and so protected from contact with, or radiation from, the flames. A blank space has been left at the foot of this form, and any general information as to the conditions of the weather during the test, as to anything abnormal which occurred, or anything else which might help to explain the results obtained, should be stated here. In particular, information should be given as to the amount of smoke shown during the test. Diagrams[1] of different intensities of smoke were submitted to the Committee by the late Mr. Bryan Donkin, and a form for plotting smoke observations by reference to these diagrams is shown in *Fig. 12.*

BOILER. Sheet II.

Line 13.—If the fuel used was coal the name of the colliery should be given, and the quality, such as nuts, slack, etc., should also be stated. If any patent fuel or oil was employed, sufficient particulars should be supplied to enable it to be identified.

Line 14.—This line should give the total weight of fuel placed upon the fires per hour, and the condition in which it was used; the figures will be obtained by dividing the total weight of fuel used by the total running time.

[1] Each set of the forms, to be obtained at the Institution, will be accompanied by a Plate of smoke-intensity diagrams.

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Line 15.—Information should be given in the remarks column as to whether a special analysis was made of the coal actually used during the trial, or whether the analysis is that of coal of a similar quality from the same colliery made at some previous date.

Line 16.—The moisture in the fuel as fired should be determined from the sample sent for chemical analysis, as pointed out on p. 247 of Appendix I.

Line 17.—Full information should be given as to the kind of calorimeter which was used for determining the calorific value of the fuel, and whether the determination was made by a chemist or some other expert.

The Committee do not consider it desirable to give any formula for calculating the heating value of a fuel from the chemical analysis. Practically all the formulas which are given in text-books and by authorities are of the following form:—Heating value of the fuel per pound =

$$(\mathrm{C} \times \text{a constant}) + \left(\left(\mathrm{H} - \frac{\mathrm{O}}{8}\right) \times \text{a constant}\right) + (\mathrm{S} \times \text{a constant})$$

where C, O, H, and S represent the percentages of carbon, oxygen, hydrogen and sulphur respectively present in the fuel, as determined by the chemical analysis, and the constants are the heating values per pound of pure carbon, hydrogen and sulphur. It is desirable to point out, however, that the percentage of oxygen in a fuel analysis is practically a fictitious figure, for it is always an undetermined quantity obtained by difference and written as ("O, etc.") in the analysis; it thus contains all the errors of the analysis. A formula of the foregoing type assumes that the amount of oxygen present and the condition of its combination are known accurately; but neither of these conditions is known with any degree of certainty. If the results obtained by calculation, using formulas of the foregoing type, be compared with those obtained by actual combustion of the fuel in a calorimeter, it will be found that a formula which assumes that the whole of the carbon and the hydrogen exist as such and entirely uncombined gives results which are too high; but, on the other hand, a formula which employs the factor $\left(\mathrm{H} - \frac{\mathrm{O}}{8}\right)$ gives results which are too low. In view, therefore, of the uncertainty of present knowledge as to the conditions of combination which obtain in any fuel, it seemed to the Committee inadvisable to adopt any formula which pretends to any degree of accuracy, and it appeared better frankly to own that any formula which can be used is an approximate one only, and that it should be used merely as a check, or in the few cases

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in which it is impossible to obtain a calorimetric determination of the calorific value of the fuel. The most recent determination of the calorific values of carbon and hydrogen are the following:—

Carbon when converted to CO_2	14,544 B.Th.U.
Hydrogen	52,200 „

the products of combustion in the latter case being assumed to remain in the form of steam. These figures can be used in calculations based on any of the ordinary formulas.

Line 18.—The carbon value of the dried fuel is obtained by dividing the calorific value of one pound of the dried fuel given on line 17 by the calorific value of one pound of pure carbon (= 14,544 B.Th.U.).

Line 19.—The figure for this line is obtained by dividing the total amount of ash and clinker formed during the trial by the number of hours during which the trial lasted.

Line 20.—The amount of carbonaceous matter in the ash can be obtained, as stated on page 252 in Appendix I., by forwarding samples to a chemist, or by calculation, based on the previous chemical analysis of the coal, of the amount of ash and clinker which ought to be formed from the amount of fuel which has been burnt. In many cases, however, *e.g.*, when forced draught is used, it will be found that the actual amount of clinker and ash collected is less in total weight than the amount which ought to be present as shown by the chemical analysis, much of it having been blown up the chimney.

Line 21.—In the column "Remarks," particulars should be given as to where the gas for analysis was taken from, and whether the aspiration was continuous or intermittent; in the blank lines at the bottom of the form a brief description of the apparatus employed for collecting the gas may be given with advantage.

Line 22.—The kind of thermometer or pyrometer employed should be stated in the column for remarks, and the position in which it was placed should also be described.

Line 23.—The mean specific heat of the products of combustion can be calculated as soon as an analysis has been made of the dry furnace gases; the method of making the calculation is explained in detail in connection with the explanations given later for determining the heat losses corresponding to lines 39 and 40 of the forms.

Lines 24–29 *and* 32.—An explanation should be given as to how the various temperatures, pressures and draughts were measured, and it should be stated how frequently the observations were taken.

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Line **30.**—Wherever possible the amount of steam employed in producing the draught (whether an actual steam-jet is used or whether the steam is used in working an engine for driving fans) should be given, and it should be determined by an independent test.

Line **31.**—Some brief explanation should be given as to the method of determining the weight of the feed-water, that is, whether it was measured by a system of tanks or whether by use of a meter or by any other method.

Line **33.**—In the column "Remarks," information should be given as to whether the gauge has been tested for accuracy, and the same remark applies to other gauges wherever such observations occur on the forms.

Line **34.**—This is obtained by adding the atmospheric pressure (line 25) to the gauge pressure (line 33).

Line **35.**—Full information should be given as to the method of determining the weight of the moisture present in the steam, and how it was trapped or collected and weighed.

Line **36.**—The temperature of saturation corresponding to the absolute steam pressure (line 34) can be obtained from any reliable steam-tables.

Blank lines are left at the bottom of this form for additional information upon any points in respect of which further details can be given with advantage.

BOILER. Sheet III.

Line **37.**—This is merely a repetition of line 17 on Sheet II.

Line **38.**—The heat transferred to the water should be calculated by one or other of the following formulas:—

(*a*) When the steam is not superheated—

$$\text{B.Th.U.} = W(H_1 - h_0) - w(H_1 - h_1)$$

(*b*) When the steam is superheated—

$$\text{B.Th.U.} = W(H_1 - h_0) + 0{\cdot}48(t_s - t_1)$$

In these formulas W = weight of steam and water leaving the boiler per pound of dried fuel. This last figure is obtained by dividing the figures on line 31 by those on line 14, after the figures on line 14 have been diminished by the weight of moisture present in the fuel (obtained by multiplying together the figures on lines 14 and 16). Hence—

$$W = \left(\frac{\text{Line 31}}{\text{Line 14} - (\text{Line 14} \times \text{Line 16})}\right)$$

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w = weight of water per pound of dried fuel leaving the boiler, and will equal (W × line 35).

t_0, t_1, and t_s are the temperatures of the feed-water, of the saturated steam at the boiler pressure, and of the steam leaving the superheater respectively (lines 32, 36, 72).

H_1 is the total heat of a pound of saturated steam at the temperature t_1.

h_0 and h_1 are the B.Th.U. in a pound of water at the corresponding temperatures t_0 and t_1.

The quantities h_0 h_1, and H_1 can be obtained from any reliable steam-table, care being taken that they are all measured from the same temperature, usually 32° F.

The following approximate formulas may be used for calculating the heat transferred to the water when no steam-tables are at hand:—

(*a*) When the steam is not superheated—

$$\text{B.Th.U.} = W(1{,}114 + 0{\cdot}305(t_1 - t_0)) - w(1{,}114 - 0{\cdot}7\,t_1)$$

(*b*) When the steam is superheated—

$$\text{B.Th.U.} = W(1{,}114 + 0{\cdot}305(t_1 - t_0)) + 0{\cdot}48(t_s - t_1)$$

The following example illustrates the use of this formula. In a boiler trial the absolute steam pressure (line 34) was 179·6 lbs. per square inch; the corresponding temperature of saturation (line 36) was 373° F.; the temperature of the feed to the boiler (line 32) was 106°; the total fuel fired per hour was 942 lbs., containing 1·94 per cent. of moisture (lines 14 and 16); and the total feed-water entering the boiler was 8,616 lbs. per hour (line 31), the total moisture present in it being 2·87 per cent. (line 35); the steam used was therefore not superheated.

$$W \text{ in this case} = \frac{8{,}616}{942 - 942 \times 0{\cdot}0194}$$

$$= \frac{8{,}616}{923{\cdot}7}$$

$$= 9{\cdot}33 \text{ lbs.}$$

$$wl = 9{\cdot}33 \times 0{\cdot}0287 = 0{\cdot}27 \text{ lb.}$$

From the steam tables $H_1 = 1{,}196$ B.Th.U.

" " " $h_1 = 345$ B.Th.U.

" " " $h_0 = 74$ B.Th.U.

Hence the B.Th.U. in this case

$$= 9{\cdot}33(1{,}196 - 74) - 0{\cdot}27(1{,}196 - 345)$$

$$= 10{,}238$$

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Lines 39 *and* 40.—In order to determine the number of heat-units carried away from the boiler by the products of combustion and the excess air, the following data are required:—A chemical analysis of the dry flue gases, the temperature of the external air, the temperature at which the gases leave the boiler, and an analysis of the fuel. The analysis of the dry gases is always made volumetrically, and the first step is to convert this into an analysis by weight. An example will most readily show how this can be done.

——	Analysis by Volume.	Atomic Weight of Gas.
Carbonic acid	0·082	22
Carbonic oxide	0·000	14
Oxygen	0·112	16
Nitrogen	0·806	14

By multiplying each of the volume proportions by the corresponding atomic weights, adding the results so obtained, and then dividing each product by the sum, the proportion by weight of each gas present is obtained.

			Proportion by Weight.
CO_2	= 0·082 × 22 = 1·804	=	0·121
CO	= 0·000 × 14 = 0·000	=	0·000
O	= 0·112 × 16 = 1·792	=	0·120
N	= 0·806 × 14 = 11·284	=	0·759
	14·880		1·000

It may be assumed that the whole of the carbon present in these gases came from the fuel which was burnt, but in CO_2 the proportion of carbon by weight is 3 : 11 and in CO it is 3 : 7, hence the actual weight of carbon present in a pound of dry flue gases is readily calculated by the following formula:—

Weight of carbon in 1 lb. of dry flue gases =

$\frac{3}{11}$ (proportion by weight of CO_2) + $\frac{3}{7}$ (proportion by weight of CO).

Employing the above example, the weight of carbon in 1 lb. of dry gas

$$= (0{\cdot}121 \times \tfrac{3}{11}) + (0{\cdot}000 \times \tfrac{3}{7}) = 0{\cdot}033 \text{ lb.}$$

The analysis of the dried fuel gives the weight of carbon in 1 lb. of it, and hence it is now possible to calculate at once how many pounds of dry flue gases leave the boiler flues per pound of dried fuel burnt. The weight of dry flue gases per pound of carbon burnt will be $\left(\frac{1}{\text{weight of C present in 1 lb. of dry flue gases}}\right)$

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= say, x lbs.; and the weight of dry flue gases per pound of dried fuel burnt will equal (x × weight of C in 1 lb. of dried fuel).

In the trial from which the figures used in this example are taken, the analysis of the dried fuel gave the following results:—

Carbon	0·840
Hydrogen	0·056
Ash	0·030
Oxygen and other matters (by difference)	0·074
	1·000

Hence the weight of dry flue gases per pound of carbon burnt was $\frac{1}{0\cdot033} = 30\cdot30$ lbs., and the weight of dry flue gases per pound of dried fuel burnt was $30\cdot30 \times 0\cdot840 = 25\cdot45$ lbs.[1] In addition to the dry flue gases, there is a certain weight of steam present in the products of combustion due to the combustion of the hydrogen of the fuel, and this weight will be nine times the weight of the hydrogen originally present in the fuel; therefore in the example the weight of steam in the flue gases is equal to $0\cdot056 \times 9 = 0\cdot50$ lb.

Therefore, the total weight of the flue gases per pound of dried fuel was $25\cdot45 + 0\cdot50 = 25\cdot95$ lbs.

The combustible matter in a pound of dried fuel burnt on the grate in this example was 0·926 lb. Hence the weight of air drawn into the flues per pound of dried fuel burnt was $25\cdot95 - 0\cdot93 = 25\cdot00$ lbs. practically, and this is the figure to enter in line 55.

A considerable proportion of this is excess air over and above that which was needed for the complete combustion of the fuel; the weight of air needed for the perfect combustion of any fuel can be readily determined by the following formula:

Weight of air per pound of fuel =
(11·56 × carbon percentage) + (34·67 × hydrogen percentage).

In the above example the weight of air theoretically needed $= 0\cdot840 \times 11\cdot56 + 0\cdot056 \times 34\cdot67 = 11\cdot65$ lbs. per pound of fuel. Hence the excess air used per pound of dried fuel burnt in this trial was $25\cdot00 - 11\cdot65 = 13\cdot35$ lbs.

Another method of determining the weight of air admitted to the furnaces per pound of dried fuel burnt, also employing the analysis of the flue gases, is the following:—It may be assumed within the limits of errors of observation that all the carbon in the

[1] The weight of dry gases per lb. of carbon burnt is also—

$$= \frac{11\ CO_2 + 8\ O + 7\ (CO + N)}{3\ (CO_2 + CO)},$$

where CO_2, O, CO, and N are the proportions by *volume* of each of those gases.

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gases came from the fuel burnt, and all the nitrogen from the air; but the proportion by weight of nitrogen to carbon in the dry flue gases is readily calculated; in the example it is $\frac{0{\cdot}759}{0{\cdot}033} = 23 : 1$. Hence for every pound of carbon burnt 23 lbs. of nitrogen must have been drawn in from the air; but in the atmosphere nitrogen is present in the proportion by weight of 76·8 parts out of every 100; hence the weight of air which was drawn into the furnaces per pound of carbon must have been $\frac{23{\cdot}00 \times 100}{76{\cdot}8} = 29{\cdot}94$ lbs. But a pound of dried fuel only contained 0·840 lb. of carbon; therefore, the weight of air drawn into the furnace per pound of the dried fuel burnt was $0{\cdot}840 \times 29{\cdot}94 = 25{\cdot}14$ lbs., which agrees very closely with the figure 25·00 obtained by the other calculation.

The general formula for this second method may be expressed thus:—

$$\text{Weight of air per pound of fuel burnt} = \frac{\text{percentage of N by weight}}{\text{percentage of C by weight}} \times \frac{100}{76{\cdot}8} \times \text{weight of C in 1 lb. of dried fuel.}$$

Lines 39 and 40 of the form may now be readily calculated. The total weight of the flue gases per pound of dried fuel has been determined, and the weight of the excess air; in the example these were respectively 25·95 and 13·35 lbs., and their difference (in the example 12·60) will be the weight of the products of combustion. The specific heat of air being 0·238, line 40 is at once calculated by multiplying the weight of excess air by its specific heat, and by the difference of temperature between the flue gases and the air, the latter two temperatures being given in lines 22 and 24; or heat carried away in excess air = weight of excess air per pound of dried fuel $\times$ 0·238 $\times$ $(t_g - t_a)$.

In the example the temperatures were respectively 452° and 62°; therefore, the heat carried away in the excess air = $13{\cdot}35 \times 0{\cdot}238 \times (452 - 62) = 1{,}239$ B.Th.U.

To calculate the heat carried away by the products of combustion their mean specific heat must be determined, and this will also give the data to fill up line 23 of the form.

The proportion by weight of each of the constituents CO_2, CO, N, and H_2O in the products of combustion produced per pound of dried fuel burnt must first be determined. The weight of CO_2 generated per pound of dried fuel burnt in this example is obtained by multiplying the weight of carbon in 1 lb. of dried fuel by the

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fraction $\frac{11}{3}$; hence the weight of $CO_2 = 0{\cdot}84 \times \frac{11}{3} = 3{\cdot}08$ lbs. The weight of CO in the example is nil, since none is shown in the analysis of the gases. If CO had been present in the gases, it would have been first necessary to find the proportion by weight of the carbon in 1 lb. of dried fuel burnt into CO_2 and CO respectively, thus :—

Proportion by weight of C burnt to CO_2

$$= \frac{\frac{3}{11}\text{ (weight of } CO_2 \text{ in 1 lb. gas)}}{\frac{3}{11}\text{ (weight of } CO_2 \text{ in 1 lb. gas)} + \frac{3}{7}\text{ (weight of CO in 1 lb. gas)}}$$

Then the weight of CO_2 formed per pound of dried fuel burnt would have been equal to $\frac{11}{3}$ × weight of C in 1 lb. dried fuel × proportion by weight of C burnt to CO_2, and similarly the weight of CO would be determined by using $\frac{7}{3}$ as the multiplying fraction.

The weight of H_2O formed per pound of dried fuel has been already determined; in the example it is 0·50 lb.

The weight of nitrogen will be equal to the total weight of the products of combustion, less the weight of CO_2, CO and H_2O; or, in the example, weight of N = 12·60 − (3·08 + 0·5) = 9·02 lbs.

The proportions by weight of each of the constituents are now readily determined. They are :—

$$CO_2 = \frac{\text{weight of } CO_2}{\text{total weight of products of combustion}} = \frac{3{\cdot}08}{12{\cdot}60} = 0{\cdot}244.$$

$$CO = \frac{\text{weight of CO}}{\text{total weight of products of combustion}} = \frac{0}{12{\cdot}60} = 0{\cdot}00.$$

$$H_2O = \frac{\text{weight of } H_2O}{\text{total weight of products of combustion}} = \frac{0{\cdot}50}{12{\cdot}60} = 0{\cdot}039.$$

$$N = \frac{\text{weight of N}}{\text{total weight of products of combustion}} = \frac{9{\cdot}42}{12{\cdot}60} = 0{\cdot}717.$$

The mean specific heat of the products of combustion (line 23) will be found by multiplying each of these weights by the corresponding specific heats of the respective gases and adding the results. The following are the specific heats of these gases :—

Nitrogen	= 0·244
CO	= 0·245
CO_2	= 0·216
H_2O	= 0·480

In the example, therefore, the mean specific heat of the products of combustion (line 23) is 0·244 × 0·216 + 0·480 × 0·039 + 0·244 × 0·717 = 0·246.

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The heat carried away in the products of combustion (line 39) can now be calculated; it is equal to: weight of products of combustion per pound of dried fuel × (flue-gas temperature − air temperature) × specific heat just found; or, in the example, the heat in B.Th.U. = 12·60 × (452 − 62) × 0·246 = 1,209.

Line 41.—The moisture in the fuel has to be warmed up from the temperature of the coal (which may be assumed to be that of the air) before it is thrown on to the fire to 212° F.; it is evaporated at this temperature and superheated to the temperature of the escaping flue-gases.

The heat expended per pound of dried fuel burnt is therefore equal to (weight of moisture present in the dried fuel per pound (line 16) × [(212° − air temperature) + 966 + 0·48 (flue-gas temperature − 212°).]

Hence, in the example, heat expended per pound of dried fuel burnt—

$$= 0{\cdot}019\,((212 - 62 + 966) + 0{\cdot}48\,(452 - 212))$$
$$= 24 \text{ B.Th.U.}$$

Line 42.—Heat lost by incomplete combustion.

This is equal to the weight of carbon burnt into CO per pound of dried fuel burnt, multiplied by the difference between the calorific value of carbon when burnt to CO_2 and when burnt to CO.

As in the example no CO was produced, it will be assumed, for a numerical example, that the proportion of carbon burnt into CO was 12·4 per cent., and that the weight of C in 1 lb. of dried fuel was 0·7716 lb, then the heat lost

$$= 0{\cdot}7716 \times 0{\cdot}124 \times (14{,}544 - 4343) = 976 \text{ B.Th.U.}$$

Line 43.—Heat lost by unburnt carbon in the ash.

This is equal to—

$$\frac{\text{Carbonaceous matter in ash per hour (line 20)}}{\text{Weight of dried fuel burnt per hour (line 14} \times \text{line 16)}} \times 14{,}544$$

or, in the example—

$$= \frac{15{\cdot}3}{923{\cdot}7} \times 14{,}544$$
$$= 241 \text{ B.Th.U.}$$

The foregoing calculations are all that are necessary for working out a complete heat-account for a boiler from the data obtained during the test.

Line 45.—This is obtained by multiplying the weight of dried fuel burnt per hour (line 14 − line 14 × line 16) by the heat

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transferred to the water per lb. of dried fuel (line 78), and dividing the product by the number of square feet of the heating surface as given on line 8.

$$\textit{Line } 46 = \frac{\text{line } 14}{\text{line } 6}.$$

$$\textit{Line } 47 = \frac{\text{line } 14 - \text{line } 14 \times \text{line } 16}{\text{line } 6}.$$

$$\textit{Line } 48 = \frac{\text{line } 31 - \text{line } 31 \times \text{line } 35}{\text{line } 14}.$$

Line 49 is line 48 multiplied by the evaporation factor, and the evaporation factor is equal to the total heat required to evaporate a pound of steam under boiler conditions, divided by 966; *i.e.*, it is equal to $\frac{H_1 - h_0}{966}$.

For values of H_1 and h_0 see line 38.

$$\textit{Line } 50 = \frac{\text{line } 31 - \text{line } 31 \times \text{line } 35}{\text{line } 14 - \text{line } 14 \times \text{line } 16}.$$

Line 51 = line 50 multiplied by evaporation factor.

Line 52 = line 51 divided by line 18.

$$\textit{Line } 53 = \frac{(\text{line } 31 - \text{line } 31 \times \text{line } 35) \times \text{evaporation factor}}{\text{line } 8}.$$

$$\textit{Line } 54 = \frac{\text{Weight of feed in lbs. per second (line 31)} \times \text{volume of 1 lb. of boiler steam in cubic feet (from steam tables).}}{\text{Area of water surface at working level in square feet (line 11).}}$$

Line 55.—This is obtained in the calculation for lines 39 and 40.

$$\textit{Line } 56 = \frac{\text{Weight of air actually used per pound dried fuel}}{\text{Weight of air theoretically needed per pound dried fuel}}$$

and both these quantities have been calculated already in the work needed for filling in lines 39 and 40.

ECONOMISER AND SUPERHEATER. SHEET I.

Line 57.—In giving a description of the economiser and the arrangement of the flues, the name of the economiser, if it is of a well-known type, should be stated, and as full particulars as possible should be supplied as to the arrangements for scraping the tubes, and the position of the economiser relative to the boiler and to the chimney, and any other details which would be of

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service in following the working of the economiser. An outline sketch will frequently be found more serviceable in simplifying the necessary written description. Particulars should be given as to the number, size, and length of pipes, etc.

Line **58.**—The figure for this line should give the total effective heating-surface of the economiser.

Line **59.**—Here again the name of the superheater, if it is of a well-known type, should be stated, and in that case generally a brief description of the method of working the superheater will be sufficient. If the superheater is of some unusual type, a full account of its construction and arrangements should be given, and in particular the method of regulating the amount of superheat. This form is only intended for use where the superheater is part of the boiler proper; if it is a superheater separately fired, then all its records should be entered upon an ordinary boiler sheet, and not upon this form at all.

Line **60.**—The total amount of effective heating-surface should be stated in this line, and it is advisable to give some of the measurements for determining this heating surface, as, for example, if it is a superheater with pipes, the diameter, length and thickness of the pipes should be stated.

Line **61.**—This quantity is the total amount of measured feed during the test (see p. 248 of Appendix I.) divided by the number of hours during which the test lasted; if there are no leaks in the economiser or through the feed-pump gland, or no loss through the economiser safety-valve, it should be the same figure as that on line 31 of the Boiler Sheets.

Lines **62-65.**—All these temperatures should be measured close to the points of entry into, or escape from, the economiser, at perfectly regular intervals throughout the run, and the mean of these observations after correction, if any is required for thermometer errors, should be entered in these lines. The kind of thermometer used should be stated in the remarks column.

Line **66.**—The instructions already given in reference to line 21 of the Boiler Sheet apply to this line.

Line **67.**—The mean specific heat of the flue-gases should be calculated as follows:—

The calculation requires (*a*) the analysis of the fuel; (*b*) a volume analysis of the flue gases as they leave the economiser.

The method can be best explained by an actual example. During a test of an economiser, samples of the gases were collected, and an analysis of the fuel burnt in the boiler was made at the conclusion of the trial, with the following results:—

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ANALYSIS OF FUEL.

C	0·782
H	0·0513
Ash	0·0233
Nitrogen, Oxygen, etc.	0·1434
	1·0000

MEAN COMPOSITION OF DRY GASES BY VOLUME.

CO_2	9·41
CO	0·26
O	10·98
N	79·35
	100·00

The first step will be the conversion of analysis by volume into analysis by weight. The method of doing this has been previously explained in the notes referring to lines 39 and 40.

ANALYSIS OF DRY GASES BY WEIGHT.

CO_2	13·83
CO	0·24
O	11·73
N	74·20
	100·00

In 100 lbs. of flue gases there are therefore $(\frac{3}{11} \times 13{\cdot}83) + (\frac{3}{7} \times 0{\cdot}24)$ lbs. of carbon, all of which may be assumed to have come out of the fuel; that is, there are in 100 lbs. of dry flue gases 3·875 lbs. of carbon. But if 3·875 lbs. of carbon correspond to 100 lbs. of dry flue gases, it is very easy to determine how many pounds of dry flue gases correspond to the combustion of 1 lb. of fuel, which only contains, from its analysis, 0·782 lb. of carbon.

The weight of dry flue gases per pound of dried fuel will be $\frac{100 \times 0{\cdot}782}{3{\cdot}875} = 20{\cdot}18$ lbs., but in addition the flue gases contain a small quantity of water, produced by the combustion of the hydrogen in the fuel, and its weight will be nine times the weight of the hydrogen in a pound of dried fuel, or in the example $= 0{\cdot}0513 \times 9 = 0{\cdot}46$ lb.

The actual weight of each constituent in the gases due to 1 lb. of dried fuel may now be determined:—

Constituent.				Weight in lbs. per lb. of dried Fuel burnt.			Weight in lbs. of each gas in 1 lb. of dry gas.
CO_2	=	20·18	×	0·1383	=	2·791	= ·1352
CO	=	,,	×	0·0024	=	0·048	= ·0023
O	=	,,	×	0·1173	=	2·367	= ·1147
N	=	,,	×	0·7420	=	14·974	= ·7255
H_2O	=					0·460	= ·0223
						20·640	1·000

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The mean specific heat of the flue gases as they leave the economiser is equal to:—

(weight of CO_2 × 0·216) + (weight of CO × 0·248) + (weight of O × 0·218) + (weight of N × 0·244 + (weight of H_2O × 0·480)

or in the example selected it is—

(0·1352 × 0·216) + (0·0023 × 0·248) + (0·1147 × 0·218) + (0·7255 × 0·244) + (0·0223 × 0·480) = 0·243.

Line **68.**—The figure for this line should be the same as that of line 31 of the Boiler Form, unless any corrections are necessary for leaks from the boiler.

Line **69.**—Unless a special pressure-gauge is fitted to the steam-pipe as it enters the superheater, this pressure must be taken as equal to the boiler pressure (line 34).

Line **70.**—A short statement should be given in the remarks column as to the method adopted for determining the percentage of moisture present in the steam as it enters the superheater. If it is considered desirable, as for example, if some special and little known method has been adopted, a full account should be given on a separate sheet attached to the report.

Lines **71–74.**—The explanations given for lines 62–65 apply equally to these four lines. It is especially desirable that full particulars should be given as to how frequently these temperatures were taken and the kind of thermometer used.

Line **75.**—See notes on line 21 of Boiler Form.

Line **76.**—See notes on line 67.

ECONOMISER AND SUPERHEATER. Sheet II.

Line **77.**—This line is the sum of lines 39 and 40 of Boiler Sheet No. III., if the waste gases pass straight to the economiser from the boiler flues; if, however, they first pass through a superheater, the figure for this line will be the same as in line 83.

Line **78.**—This line is obtained by multiplying the weight of the feed per pound of dried fuel by the rise of temperature of the feed in passing through the economiser—

$$= \frac{(\text{line } 61)}{(\text{line } 14 - \text{line } 14 \times \text{line } 16)} \times (\text{line } 63 - 62)$$

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Line 79.—The calculations necessary for filling in this line are precisely similar to those given for lines 39 and 40. The weight of the chimney gases per pound of dried fuel burnt must be determined, and then the heat carried off in them is equal to: weight of chimney gases per pound of dried fuel × mean specific heat (line 67) × excess of temperature on leaving economiser above that of atmosphere (lines 65 − line 24). Using the data already assumed in the example worked out for line 67, the following calculations may serve as an illustration:—

Taking the data from the example already given for line 67—

Weight of chimney gases per pound of dried fuel .	= 20·64 lbs.
Mean specific heat of these gases (line 67) . . .	= 0·243
Temperature of gases leaving economiser . . .	= 411° F.
Temperature of air	= 49° F.

Hence the heat carried off by the chimney gases per pound of dried fuel = 20·64 × 0·243 × (411 − 49) = 1816 B.Th.U.

Line 80 = line 77 − (line 78 + line 79).

Line 81.—This line is the sum of lines 39 and 40 of the boiler sheet, if the waste gases pass straight from the boiler-flue to the superheater.

Line 82.—This line should be calculated as follows:—

w = weight of moist steam entering the superheater per pound of dried fuel = $\dfrac{\text{line 68}}{(\text{line 14}) - (\text{line 14} \times \text{line 16})}$.

x = moisture in 1 lb. of steam (line 70).

t_1 = temperature of moist steam as it enters superheater (line 71).

t_2 = temperature of superheated steam as it leaves superheater (line 72).

Then heat transferred to steam per pound of dried fuel burnt = $(x \times w \times (1114 - 0{\cdot}71\ t_1)) + (w\ (t_2 - t_1)\ 0{\cdot}48)$ B.Th.U.

Line 83.—The calculations to obtain the figures for this line are similar in all respects to those already given for line 79.

The heat carried off in the chimney gases = weight of gases per pound of dried fuel × line 76 × (line 24 − line 74).

Line 84 = line 81 − (line 82 + line 83).

Line 85 = $\dfrac{\text{weight of dried fuel burnt per hour} \times \text{line 78}}{\text{line 58}}$;

or $= \dfrac{(\text{line 14} - (\text{line 16} \times \text{line 14}))\ \text{line 78}}{\text{line 58}}$.

Line 86.—This line is obtained in the same way as line 85, using line 82 in place of line 78, and line 60 in place of line 58,

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i.e. heat transmitted per square foot of surface of superheater per hour—

$$= \frac{(\text{line } 14 - (\text{line } 16 \times \text{line } 14))\ \text{line } 82}{\text{line } 60}.$$

Line **87.**—This line is the ratio of the whole amount of heat passed into the feed per pound of dried fuel to the whole amount of heat available from the combustion of a pound of dried fuel

$$= \frac{\text{line } 38 + \text{line } 78 + \text{line } 82}{\text{line } 37}.$$

ENGINE. Sheet I.

Line **88.**—If the engine is of a well-known make, it will be sufficient to state so, and then to give a few leading dimensions. The following example will illustrate this.

Inverted vertical marine, triple expansion, surface condensing. The cylinders were placed in the order—intermediate, high, low; and the cranks rotate in the sequence—high, intermediate, low. The high-pressure cylinder alone was jacketed, the steam for this jacket coming direct from the boiler, the drain from the jacket in ordinary work passing straight to the hot-well. Two feed-pumps, one circulating-pump, one air-pump, and two bilge-pumps were driven by levers from the crosshead of the low-pressure cylinder.

Line **89.**—The following example will illustrate the information which should be given.

The H.P. and L.P. cylinders were fitted with ordinary double-ported slide-valves; the I.P. cylinder had a Trick slide-valve. None of these valves were balanced, and they were driven by the ordinary Stephenson link-motion.

It is desirable to state here whether the valves were specially tested for leakage before the trial.[1]

Line **90.**—A full statement of the kind of governor in use, and whether it merely operated a throttle-valve or varied the cut-off of the steam, should be given in this line.

Line **91.**—State whether the feed to the boiler, or the discharge from the air-pump hot-well, was measured, also whether a system of tanks or a tumbling-bay or meter was used.

Lines **92–99.**—All these dimensions should be given with the greatest possible accuracy; the diameters of the cylinders should

[1] Absence of leakage when stationary is no guarantee of tightness when valves are in motion. (See Minutes of Proceedings Inst. C.E., vol. cxxxi. pp. 174–214.)

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Line 78.—The calculations necessary for filling in this line ar
precisely similar to those given for lines 39 and 40. The weigh
of the chimney gases per pound of dried fuel burnt must be det
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of chimney gases per pound of dried fuel × mean specific h
(line 66) × excess of temperature on leaving economiser ab
that of atmosphere (lines 65 − line 24). Using the data alre
assumed in the example worked out for line 67, the follow
calculations may serve as an illustration:—
Taking the data from the example already given for line 67

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Mean specific heat of these gases (line 67)	= 0·243
Temperature of gases leaving economiser	= 411° F.
Temperature of air	= 49° F.

Hence the heat carried off by the chimney gases per pou
dried fuel = 20·64 × 0·243 × (411 − 49) = 1816 B.Th.U.
Line 80 = line 77 − (line 78 + line 79).
Line 81.—This line is the sum of lines 39 and 40 of the
sheet, if the waste gases pass straight from the boiler-flue
superheater.
Line 82.—This line should be calculated as follows:—

$$w = \text{weight of moist steam entering the superheater of dried fuel} = \frac{\text{(line 14) − (line 14 × line 16)}}{\text{line 68}}$$

x = moisture in 1 lb. of steam (line 70).
t_1 = temperature of moist steam as it enters
(line 71).
t_2 = temperature of superheated steam as it leave
(line 72).
Then heat transferred to steam per pound of dried
= ($w \times$ [illegible] − 0·71 t_2)) + (w ($t_2 - t_1$) 0·48) B.Th
Line [illegible] calculations [illegible] in the figures fo
same si[illegible] specta to [illegible] dy given for lin
T[illegible] off in the [illegible] ases = weight
po[illegible] × line 7[illegible] − line 74).
[illegible] 81 − (li[illegible] 8).
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$$\frac{\text{[illegible]}}{\text{[illegible] 14)) line 78}}$$

[illegible] the same wa
[illegible] line 80 in pla

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i.e. heat transmitted per square foot of surface of superheater per hour—

$$= \frac{(\text{line } 14 - (\text{line } 16 \times \text{line } 18)) \text{ line } 82}{\text{line } 60}.$$

Line 87.—This line is the ratio of the whole amount of heat passed into the feed per pound of dried fuel to the whole amount of heat available from the combustion of a pound of dried fuel

$$= \frac{\text{line } 38 + \text{line } 78 + \text{line } 82}{\text{line } 37}.$$

ENGINE. Sheet I.

Line 88.—If the engine is of a well-known make, it will be sufficient to state so, and then to give a few leading dimensions. The following example will illustrate this.

Inverted vertical marine, triple expansion, surface condensing. The cylinders were placed in the order—intermediate, high, low and the cranks rotate in the sequence—high, intermediate, low. The high-pressure cylinder alone was jacketed, the steam for this jacket coming direct from the boiler, the drain from the jacket joining ordinary work passing straight to the hot-well. Two feed-pumps one circulating-pump, one air-pump, and two bilge-pumps were driven by levers from the crosshead of the low-pressure cylinder.

Line 89.—The following example will illustrate the information which should be given.

The H.P. and I.P. cylinders were fitted with ordinary double ported slide-valves; the L.P. cylinder had a Trick slide. None of these valves were balanced, and they were driven by ordinary Stephenson link-motion.

It is desirable to state here whether the valves were tested for leakage before the trial.

Line 90.—A full statement [illegible]

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be measured if possible at the time of the trial, gauges being made for each cylinder. Where no other means of determining clearance volumes and surfaces is available, they should be calculated by measurements off the drawings from which the engines were made, but cylinder clearance volumes should, whenever it can be done, be determined accurately by filling the spaces with water at a known temperature.

ENGINE. SHEET II.

Line **100.**—Give the total length of the trial in hours and decimals.

Line **101.**—State whether a mercury barometer or an aneroid barometer was used for determining the pressure. For reducing from the barometer reading to pounds per square inch the following rule may be adopted :—

14·7 lbs. per square inch = 29·92 inches of mercury ; or,

1 inch of mercury = 0·49 lb. pressure per square inch.

Line **102.**—This is the total weight of steam used in the cylinders divided by the number of hours during which the trial lasted, the weight of steam being determined by one of the methods explained in paragraph 9 of Appendix I. p. 254.

Line **103.**—Is similarly equal to the total weight of water collected from the jacket drains divided by the duration of the trial in hours.

In collecting the water from the jacket drains attention is drawn to paragraph 8 of Appendix I. p. 253, as to the precautions necessary for preventing loss owing to the possibility of a considerable quantity of the discharge escaping in the form of steam.

If the jackets drain directly back to the boiler, a special determination should be made, on some other occasion than the actual trial, of the condensation in the jackets, when working under exactly the same conditions as in the trial itself, by temporarily disconnecting the drain from the boiler and collecting the drainage.

Line **104.**—The pressure-gauge should be read at regular intervals throughout the whole run, and the mean reading should be corrected for any errors in the gauge; and in the column for remarks it should be stated whether or not the gauge has been recently tested for errors.

The absolute pressure is obtained by adding the barometrical pressure to the mean gauge-pressure reading.

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Line 105.—This should be determined from a set of steam tables.

Line 106.—In the column for remarks a brief statement should be given as to how the moisture in the steam was determined; and if some special or unusual means was adopted, a full account of it should be given on the blank lines at the bottom of the form, or on a separate sheet attached to the report.

Line 107.—This should be the same as line 103 if there is no leakage from the jackets; and the remarks already made with reference to line 103 apply to this line.

Line 108.—This temperature should be measured, if possible, by a thermometer placed as close as possible to the exit of the jacket drains from the engine; if no other means is available the pressure may be measured by means of a gauge attached to the jacket drain at the exit, and then the temperature obtained from the mean of the pressure readings from steam-tables.

Line 109.—This pressure should be determined by means of a gauge fixed on the exhaust-pipe at the point where it leaves the engine, and regular readings should be taken and their mean corrected for any gauge errors.

Line 110.—This should be determined from steam-tables for the mean pressure given on line 109.

Line 111.—This temperature may be obtained by an ordinary mercury thermometer placed in the exhaust-pipe, close to the engine; but special precaution will have to be adopted to prevent fracture of the thermometer bulb.

Line 112.—State in the remarks column whether the mean pressures were obtained by the use of a planimeter, or by dividing up the diagrams by ordinates; also state how often sets of diagrams were taken.

Line 113.—The figure for this line will be obtained by adding to the mean effective pressure in the L.P. cylinder, the mean effective pressure in the H.P. cylinder multiplied by the fraction

$$\frac{\text{H.P. cylinder effective area}}{\text{L.P. cylinder effective area}}$$

and also the mean effective pressure in the I.P. cylinder multiplied by the fraction—

$$\frac{\text{effective I.P. cylinder area}}{\text{effective L.P. cylinder area}}$$

If the piston speeds in the various cylinders are different, a further obvious correction must be made.

Line 114.—In calculating the mean area of the cylinder, if there

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is only a piston-rod and no tail-rod, the mean area is ($0{\cdot}785\ D^2 - \frac{1}{2}\ 0{\cdot}785\ d^2$), where D is the diameter of the cylinder and d the diameter of the piston-rod (see line 92); if there is a tail-rod as well as a piston-rod the mean area will be—

$$0{\cdot}785\ D^2 - \tfrac{1}{2}\ (0{\cdot}785\ (d_1^2 + d_2^2))$$

where d_1 is the diameter of the piston-rod and d_2 the diameter of the tail-rod.

Line **115.**—The total revolutions as recorded by the counter for the whole run divided by the whole number of minutes during which the trial lasted.

Line **116.**—The average piston speed in feet per minute is equal to twice the average number of revolutions per minute multiplied by the stroke of the L.P. piston in feet, or

$$= \frac{\text{line 115} \times \text{L.P. stroke (line 92)}}{6}.$$

Line **117.**—This line is the sum of the horse-powers given on line 112.

Line **118.**—If it is possible to measure the brake horse-power, it should be given in this line, and in the remarks column a statement should be made as to how the power was measured—that is, whether by a friction brake, or by absorbing the power electrically, or any other means.

Line **119** is $\dfrac{\text{line 118}}{\text{line 117}} \times 100.$

ENGINE. Sheet III.

The method of filling up lines 120 to 130 of this form will best be illustrated by taking an actual example.

Line **120.**—The gross heat-supply entering the engine per minute will be equal to the total heat above 32° F. contained in 1 lb. of steam at the pressure given on line 104 multiplied by the weight of steam entering the engine per minute. This latter quantity will be the sum of lines 102 and 103 divided by 60.

Example.—Steam pressure (line 104), 201 lbs. absolute; the corresponding total heat of a pound of steam above 32° F. for this pressure is 1,198 B.Th.U.; weight of steam entering cylinders per hour (line 102), 1054·8 lbs.; steam passing through jackets (line 103), 158·4 lbs.; hence gross heat-supply entering engine per minute—

$$= \left(\frac{1{,}054{\cdot}8 + 158{\cdot}4}{60}\right) \times 1{,}198$$

$$= 24{,}223\ \text{B.Th.U.}$$

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Line 121.—One I.HP. per minute is equal to 42·41 B.Th.U.; hence the figure for this line is obtained by multiplying the I.HP. (line 117) by 42·41.

In the example selected the engine was developing 73·87 I.HP., hence the figure for line 121 would be—

$$42{\cdot}41 \times 73{\cdot}87 = 3{,}133 \text{ B.Th.U.}$$

Line 122.—This line will be equal to the weight of water leaving the jacket per minute multiplied by the difference between the temperature at which it leaves the engine and 32° = $\frac{\text{line } 103}{60}$ $\times (t_3 - 32)$, where t_3 is the temperature at which the water leaves the cylinder jackets. In the example selected the weight of jacket-steam per hour (line 103) was 158·4 lbs., and the temperature at which it left (line 108) was 382° F.; hence the heat passing away in the jacket drains per minute—

$$= \frac{158{\cdot}4}{60} \times (382 - 32)$$

$$= 924 \text{ B.Th.U.}$$

Line 123.—The heat leaving the engine in the exhaust steam cannot be directly calculated unless observations are made as to the quantity of condensing-water used in the condenser, and the rise of temperature of the water as it passes through the condenser. If these observations are made and the temperature of the hot-well is also measured, the figure for line 123 can be readily calculated.

The heat leaving the engine in the exhaust steam per minute = (the weight of condensing water per minute) × (the rise of temperature of the condensing water) + (the weight of condensed steam leaving the engine per minute) × (the hot-well temperature (line 110) − 32).

For example, in the above trial the weight of condensing water per hour (line 143) was 24,180 lbs., the temperature of the cooling water as it entered the condenser (line 144) was 52·26° F., and the temperature of the cooling water as it left the condenser (line 145) was 94·94° F.; hence the heat carried away in the condensing water was—

$$= \frac{24{,}180}{60} \times (94{\cdot}94 - 52{\cdot}26) = 17{,}200 \text{ B.Th.U.}$$

The heat carried away by the exhaust steam—

$$= \frac{1054{\cdot}8}{60} \times (135{\cdot}0 - 32) = 1{,}811 \text{ B.Th.U.}$$

Hence the total heat passing away from the engine per minute in the exhaust steam was:—17,200 + 1,811 = 19,011 B.Th.U.

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Line **124.**—This line is equal to line 120 minus the sum of lines 121, 122, and 123; or, in the example, 24,223 − 23,068 = 1,155 B.Th.U.

Line **125.**—In accordance with par. 3 of the recommendations of the Committee on Thermal Efficiency of Steam Engines, the heat supplied to an engine is calculated as "the total heat of the steam entering the engine less the water heat of the same weight of water at the temperature of the engine exhaust, both quantities being reckoned from 32° F."

In the example the weight of steam supplied to the engine per minute per I.HP. $= \frac{\text{line } 102 + \text{line } 103}{\text{line } 117 \times 60} = \frac{1054{\cdot}8 + 158{\cdot}4}{73{\cdot}87 \times 60} =$ 0·274 lbs.

The total heat of 1 lb. of steam (see notes on line 120) as it enters the engine (above 32°) = 1198 B.Th.U.

The water heat of 1 lb. of water (see line 111) at the exhaust temperature (above 32°) = 103 B.Th.U.

Hence the heat supplied in this case per I.HP. per minute = 0·274 (1198–103) = 0·274 × 1095 = 300 B.Th.U.

Line **126.**—This is obtained by dividing the heat equivalent to 1 HP. per minute = 42·41 × 100 by line 125; this in the example $= \frac{42{\cdot}41 \times 100}{300} = 14{\cdot}14$ per cent.

Line **127.**—The method of calculating the heat required per minute by the Institution standard of comparison per I.HP. was fully explained in the Report[1] of the Committee.

In the example the following is the working out of the formula:—

B.Th.U. per minute per HP.

$$= \frac{42{\cdot}4\,(La + Ta - Te)}{(Ta - Te)\left(1 + \frac{La}{Ta}\right) - Te \text{ hyp\_log } \frac{Ta}{Te}}$$

where Ta is absolute temperature of steam at boiler side of engine stop-valve.

Te is absolute temperature of steam at exit from engine.

La is latent heat of 1 lb. of steam at Ta.

In the example $Ta = 382 + 461 = 843$

$Te = 135 + 461 = 596$

$La = 845$

[1] Minutes of Proceedings Inst. C.E., vol. cxxxiv. p. 278.

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Hence B.Th.U. per minute per HP.

$$= \frac{42{\cdot}4\,(845 - 843 - 596)}{(843 - 596)\left(1 + \frac{845}{843}\right) - 596 \text{ hyp log } \frac{843}{596}} = 160{\cdot}6 \text{ B.Th.U.}$$

Line **128.**—This is $\frac{\text{line } 127 \times 100}{\text{line } 125} = \frac{160{\cdot}6 \times 100}{300} = 53{\cdot}5$ per cent. in the example.

Line **129.**—This will be equal to $\frac{\text{line } 125 \times 100}{\text{line } 119}$, or in the example $= \frac{300 \times 100}{79{\cdot}6} = 377.$

Line **130.**—This is the sum of lines 102 and 103 divided by line 117; or in the example $= \frac{1054{\cdot}8 + 158{\cdot}4}{73{\cdot}87} = 16{\cdot}4.$

ENGINE ACCESSORY. Sheet I.

Line **131.**—It should be stated whether a jet- or surface-condenser is used, and a short but full account should be given of the form of the condenser and its general arrangements.

Lines **132–135.**—These dimensions should be given by actual measurements from the condenser or from the working drawings.

Line **136.**—The following is the kind of description which should be given:—

The air-pump is a vertical single-acting pump 17 inches in diameter, with a stroke of 26 inches, and is driven by a lever from the cross-head of the low-pressure cylinder, the valves being formed of flexible india-rubber ½ inch thick, and provided with brass guards. The suction pipe was 3 inch diameter.

Line **137.**—A description similar to that given on line 136 will suffice in this case.

If the circulating pump is a centrifugal pump driven by an independent engine, the diameter of the pump disk and width of vanes near the periphery should be given, and also the dimensions of and power required by the independent engine, and in this case records of a test of this independent engine should be filled up in an ordinary engine sheet.

Line **138.**—The general dimensions of the feed-heater and the sizes of the various pipes and connections to the feed-pump and boiler should be given.

Line **139.**—The extent of the heating-surface should be determined by actual measurements if possible.

Line **140.**—Under this line a general description of the arrangements of the pipes and of the particular covering adopted,

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its thickness, and any other details should be given, and it should be stated whether it slopes towards the engine; state also the number of flanges and whether the flanges are covered, and the plan adopted for draining the pipes and collecting the drainage for weighing purposes.

Lines **141–142.**—These dimensions should be given from the drawings or from actual measurements made from the pipes.

ENGINE ACCESSORY. Sheet II.

Line **143.**—This will be obtained by dividing the whole quantity of cooling water used throughout the trial by the number of hours during which the trial lasted. In the column for remarks it should be stated whether the measurement of the condensation water was made by a weir, or by the use of a meter, or by a system of double tanks, or by some other method.

Lines **144–145.**—The temperatures should be read at regular intervals and the means given in these two lines, after correction if necessary, for any thermometer errors.

Line **146.**—This should be the same figure as line 102, if there are no losses of steam while passing through the engine, such as leakage past the glands of piston-rods and valve-rods; if such leakage occurs it should be determined, if possible, and deducted from the amount given in line 102, the result being then entered on this line.

Lines **147–148.**—The same remark applies to these two lines as to lines 144 and 145.

Line **149.**—State in the column for remarks whether the vacuum was measured by an ordinary vacuum-gauge or by means of a mercury column, and if a gauge was used state whether it has been recently tested for accuracy.

Line **150.**—The volume should be calculated from the dimensions of the air-pump given on line 136.

Line **151.**—Indicator diagrams should be taken at regular intervals from the pump, and the horse-power should be worked out in the ordinary way.

Lines **152–153.**—Similar remarks apply to these two lines as to the two previous lines.

Lines **154–157.**—All these temperatures should, as stated in other cases, be read at regular intervals, and the means should be given after correction for thermometer errors.

Line **158.**—The quantity of steam used by the feed-pump when it is driven by a separate engine should be determined by an independent test, which may or may not be on the same day as the

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other test. If it is on the same day, special arrangements should be made for condensing the steam in a separate condenser, and collecting the resulting water during the whole period of the test.

Lines **159–160.**—The gauges should be read at regular intervals and the means corrected for any gauge errors.

Lines **161–162.**—These temperatures, if the steam is not superheated, may be obtained directly from steam tables for the pressures given on lines 159 and 160; but if the steam is superheated the temperatures must be directly measured by thermometers and the mean temperatures given in these two lines.

Lines **163–164.**—State in the remarks column how the moisture was determined, that is, what type of calorimeter was used, and, if it is considered desirable, a separate report may be attached to the form giving full particulars of these observations.

Line **165.**—The figure for this line is obtained by dividing the whole amount of water drained off from the steam-pipes during the trial, by the number of hours during which the trial lasted, and a brief statement should be given in the remarks column as to how the water was collected.

ECONOMY OF THE COMPLETE PLANT.

Line **166.**—The figure for this line is obtained by multiplying together the number of pounds of fuel used per minute in the boiler and superheater, if separately fired, by the heating value of a pound of fuel as determined in a calorimeter.

Line **167.**—This is equal to the I.HP. $\times$ 42·41.

Line **168** = B.HP. $\times$ 42·41.

Line **169** $= \dfrac{\text{Line } 167}{\text{Line } 166} \times 100.$

Line **170** is $\dfrac{\text{Line } 168}{\text{Line } 166} \times 100$

Line **171** is equal to the total weight of fuel fired per hour divided by the I.HP.

A number of blank lines are left at the bottom of this form in which any other observations or explanations of the method of carrying out the trial may be inserted. In all cases it should be remembered that in order to compare one trial with another the relative conditions of the two trials must be accurately known, and therefore the fullest possible information should be given in all cases not only of the results of the observations, but of the way in which they were carried out.

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INDICATORS.

"On Indicators of the Watt Type." L. DE MAUPEOU. .	Vol. lxxii. p. 386.
"On the Theory of the Indicator and Errors in Indicator Diagrams." O. REYNOLDS	Vol. lxxxii. p. 232.
"On the Theory of the Indicator and Errors in Indicator Diagrams." O. REYNOLDS	Vol. lxxxiii. p. 1.
"Experiments on the Steam-Engine Indicator." A. W. BRIGHTMORE	Vol. lxxxiii. p. 20.
"Experiments on the Steam-Engine Indicator." Dr. KIRSCH	Vol. lxxxvi. p. 341.
"Contributions to the Theory of the Indicator." Dr. A. SLABY	Vol. c. p. 463
"The Influence of Temperature upon the Accuracy of Indicator Springs"	Vol. cxix. p. 461.
"Continuous Steam-Engine Indicator." T. GRAY. . .	Vol. cxxxi. p. 438.

DYNAMOMETERS AND BRAKES.

"Raffard's Friction-Dynamometer." COLLIGNON . . .	Vol. lxxi. p. 476.
"Brauer's Dynamometric Brake." H. WALTHER-MEUNIER	Vol. lxxx. p. 266.
"Friction Brake Dynamometers." W. W. BEAUMONT .	Vol. xcv. p. 1.
"On the Triple-expansion Engine, and Engine Trials at the Whitworth Laboratory, Owens College, Manchester." O. REYNOLDS. (Describes a hydraulic brake)	Vol. xcix. p. 152.
"A New Transmission Dynamometer." W. E. DALBY .	Vol. cxxxii. p. 47.

THERMOMETERS.

"On the Displacement of Zero in Thermometers." R. WEBER	Vol. xciii. p. 588.
"A Method of taking the Temperature of the Cylinder Walls of a Steam-Engine." B. DONKIN	Vol. c. p. 347.
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"On the Measurement of High Temperatures." Prof. W. C. ROBERTS-AUSTEN	Vol. cx. p. 152.
"Notes on Pyrometers and the Measurement of High Temperatures." E. DENY	Vol. cxx. p. 471.

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"The Law of Condensation of Steam deduced from Measurements of Temperature Cycles of the Walls and Steam in the Cylinder of a Steam-Engine." H. L. CALLENDAR and J. T. NICOLSON. (Contains full description of electrical thermometers) . . . . . Vol. cxxxi. p. 147.

"Thermometry." C. CHREE . . . . . Vol. cxxxv. p. 470.

"Comparison of Platinum and Gas Thermometers." J. A. HARKER and P. CHAPPUIS . . . . . Vol. cxli. p. 483.

"Platinum Gas Thermometer." L. HOLBORN and A. DAY Vol. cxliii. p. 441.

"On Platinum Pyrometers." H. L. CALLENDAR. Journal of the Iron and Steel Institute, vol. No. 1 of 1892, p. 164.

CALORIFIC VALUE AND ANALYSIS OF FUELS.

"Tests of German Coals." DR. H. BUNTE . . . . . Vol. lxxiii. p. 328.

"On the Composition and Heating Power of Ruhr Coal." SCHEURER-KESTNER . . . . . Vol. lxxxii. p. 437.

"On th Heat of Combustion of Coal." SCHEURER-KESTNER and MEUNIER-DOLLFUS . . . . . Vol. lxxxvi. p. 447

"On the Heats of Combustion and Formation of Solid Carburets of Hydrogen." BERTHELOT and VIEILLE . Vol. xc. p. 574.

"Experiments with Nixon's Navigation Coal." SCHEURER-KESTNER and MEUNIER-DOLLFUS . . . . . Vol. xciv. p. 379.

"Calorimeters for Testing Fuels on a Small Scale, with Notes on Fuel-testing Stations." B. DONKIN and J. HOLLIDAY . . . . . Vol. cii. p. 292.

"Newer Investigations on the Calorific Value of Coals." DEUTECOM . . . . . Vol. cvlii. p. 452.

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EXAMPLES OF TRIALS.

In the following pages are given sets of forms filled in with data taken from trials, in order to illustrate the method of using them. On pages 296–298 are shown the results of an ordinary Boiler Trial, the boiler having been tested independently of its accessories or of the steam-engine; on pages 299–303 are given the results of a simple test of a steam-engine, fitted with a surface-condenser, air-pump, etc.; and on pages 304–314 are shown a complete set of forms filled in with the results of an elaborate trial embracing all the different portions of the steam plant, including boilers, superheaters, economisers, engines, pumps, etc.

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I.—Trial of a Steam Plant at _____ Made on the __ ____ 19__

BOILER. Sheet I. GENERAL DESCRIPTION AND DIMENSIONS.

Type of Boiler *Two Marine (Scotch).* Made by *Messrs. The Central Marine Engine Works.*
Maker's rating of the output of the Boiler ____ lbs. of steam per hour.
Pressure for which designed *180* lbs. per square inch (gauge).
Test made at an output of *8,600* lbs. of steam per hour, at a pressure of *164* lbs. per square inch (gauge) in the presence of . . . . . .
Object of Trial *Experimental Research.*

Reference Number.	GENERAL DESCRIPTION OF BOILER AND LEADING DIMENSIONS.
1	*Single-ended marine steel boiler with Purves corrugated flues. Mean diameter of shell 13 feet 3 inches, length of shell 10 feet; two furnaces with grates 5 feet 6 inches broad by 8 feet long.*
	The tubes were 3 inches external diameter, and 6 feet 10¾ inches long, and the total number was 480.
	The heating surface was 75·2 times the grate area.
	The tube surface was 61·7 times the grate area.
	The internal diameter of the funnel was 6 feet 3 inches, and a damper was placed at a height of 17 feet 8 inches above the fire-bars.
2	Method of starting and stopping the test.—*The trial was started and finished by the method B described on page 239 of Appendix I.*
3	Method of stoking and average thickness of fire.—*The boilers were hand-fired, the average thickness of the fire being 6 inches.*
4	Production of draught.—*Forced draught, a fan in engine-room, driven by an engine supplied with steam from a donkey-boiler, forced air into a trunk across the front of the boilers, from whence it passed mainly to ash-pits, but a small quantity was also delivered into the combustion chambers.*
	Chimney, height (*above fire-bars*) *51½* ft.
5	Area at bottom *30·7* sq. ft.; top *30·7* sq. ft.
	Total grate surface (excluding dead plate) . . sq. ft. *42·0*
6	Percentage of grate area occupied by air spaces between bars *not measured.*
7	
8	Total effective heating surface fire-box (*and combustion chamber*) *570* sq. ft., tubes *2,590* sq. ft., sq. ft *3,160*
9	Capacity of water space . . at ___ inches c. ft. *not measured*
10	,, ,, steam space . . in gauge ,, ,, ,,
11	Area of water surface in boiler glass. sq. ft. ,, ,,

The forced-draught fan was 60 inches in diameter and 20 inches broad, and at 400 revolutions a minute it can deliver 14,000 cubic feet of air a minute at a pressure of 3¼ inches of water. It was driven by a Chandler single-acting high-speed engine with cylinder 8 inches in diameter and 7 inches stroke, developing 2·1 I.HP. at 180 revolutions a minute, the speed during the trial.

The average air-pressure in the trunk near the fan was 0·86 inch of water, and in the trunk at the back of the boilers 0·34 inch of water.

The funnel damper was only one-sixth open during the trial.

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II.—Trial of a Steam Plant at _____ Made on the _ _ 19_ _

BOILER. Sheet II. DATA DEDUCED FROM OBSERVATIONS.

Reference number.	Particulars of Observations.	—	Remarks.
12	Duration of trial . . . . . hours	*16*	
	FUEL.		
13	Short description	*Tyne coal*	*From Walbottle Colliery.*
14	Fired per hour . . . . . lbs.	*942*	
15	Analysis by weight of dried fuel, Carbon . . per cent.	*83·97*	*Special analysis.*
	" " " Hydrogen . . "	*5·58*	
	" " " Sulphur . . "	..	
	" " " Ash . . . "	*2·96*	
	" " " {Oxygen . . " / Other matters " }	*7·49 (by difference)*	
16	Moisture in fuel as fired . . . . . per lb.	*0·0194*	
17	Calorific value of dried fuel . . . . B.Th.U. per lb.	*14,890*	*By Thomson modified calorimeter. (Expert chemist.)*
18	Carbon value per lb. of dried fuel	*1·02*	
	ASH AND CLINKER.		
19	Total per hour . . . . . lbs.	*27·0*	*2·9* per cent. of total fuel fired.
20	Carbonaceous matter in ash per hour . . . . lbs.	*15·3*	*(Determined by analysis.)*
	FLUE GASES.	By Vol. By Weight.	
21	Analysis of dry flue gases, Carbonic Acid . . per cent.	*8·20 12·12*	*From funnel on main deck, about 13 feet above damper.*
	" " " Carbonic Oxide . "	*0·00 0·00*	
	" " " Oxygen . . . . "	*11·17 12·01*	
	" " " Nitrogen, by difference "	*80·63 75·87*	
22	Average temperature leaving boiler flues . . . ° F.	*452*	*By mercury thermometer with nitrogen above mercury at place where gases were collected.*
23	Mean specific heat of products of combustion . B.Th.U.	*0·243*	
	AIR AND DRAUGHT.		
24	Temperature of outside air . . . . . ° F.	*62*	
25	Barometric pressure (*29·67* inches mercury) lbs. per sq. in.	*14·58*	
26	Pressure in ash-pit (if forced air-supply) inches of water	*+0·17*	
27	Pressure over fire . . . . . " "	..	
28	Draught at gas exit from boiler. . . " "	..	
29	Draught at base of chimney . . . " "	*−0·25*	*At place where gases were collected.*
30	Weight of steam per hour used in producing draught lbs.	*not measured.*	
	FEED WATER.		
31	From pump, economiser or feed heater per hour . lbs.	*8,616*	
32	Temperature of feed to boiler . . . . . ° F.	*105*	
	STEAM.		
33	Gauge pressure . . . . . lbs. per sq. in.	*165·0*	*Determined by analysis of salt in boiler water and condensed steam.*
34	Absolute pressure . . . . . lbs. per sq. in.	*179·6*	
35	Total moisture in steam . . . . . per lb.	*0·0287*	
36	Temperature of saturation . . . . . ° F.	*373*	

The coal was weighed in baskets holding 450 lbs. each, and the fires were cleaned once during the trial.

The furnace gas samples were taken every hour, some slowly over periods varying from ½ to 1 hour, some quickly.

Feed water was measured by tanks, each of the pair of measuring tanks held about 15½ minutes' supply. Supplementary feed was measured in a separate tank. All gauges and thermometers were read regularly every ½ hour, and were afterwards all tested for accuracy.

NOTE.—When jacket condensed steam and re-heater condensed steam are returned direct to the boiler, the weight of each, returned per hour, should, if possible, be determined, and also the temperatures at which they enter the boiler. The blank lines are intended for use in such cases and for any other observations which it may be desired to record.

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III.—Trial of a Steam Plant at _____ Made on the _____ 19 ___

BOILER. Sheet III. HEAT ACCOUNT AND DEDUCTIONS.

Reference Number.	——	B.Th.U.	Per Cent.
	HEAT ACCOUNT (per pound of dried fuel).		
37	Total heat value of 1 lb. of dried fuel. . . .	*14,890*	*100·0*
38	Heat transferred to the water (*thermal efficiency*)	*10,238*	*68·7*
39	Heat carried away by products of combustion .	*1,209*	*8·1*
40	Heat carried away by excess air	*1,239*	*8·3*
41	Heat lost in evaporating and in superheating moisture mixed with fuel	*24*	*0·2*
42	Heat lost by incomplete combustion	*Nil*	..
43	Heat lost by unburnt carbon in ash	*241*	*1·6*
44	Balance of heat account. Errors of observation, and unmeasured losses, such as—those due to radiation, escape of unburnt hydro-carbons, superheating moisture in air, loss in hot ashes, etc.	*1,939*	*13·1*
	Total . .	*14,890*	*100·0*
	DEDUCTIONS.		
45	Heat transmitted per square foot of heating surface per hour	B.Th.U.	*2993*
46	Weight of fuel fired per square foot of grate per hour	lbs.	*22·4*
47	Weight of dried fuel fired per square foot of grate per hour	lbs.	*22·0*
48	Water evaporated per pound of fuel as fired .	lbs.	*8·88*
49	Equivalent evaporation from and at 212° F. per pound of fuel as fired	lbs.	*10·32*
50	Water evaporated per pound of dried fuel . .	lbs.	*9·06*
51	Equivalent evaporation from and at 212° F. per pound of dried fuel	lbs.	*10·53*
52	Equivalent evaporation per pound of carbon value of dried fuel from and at 212° F. . .	lbs.	*10·32*
53	Weight of feed from and at 212° F. per square foot of heating surface per hour	lbs.	*3·08*
54	Velocity of steam leaving water surface. . .	feet per second	..
55	Air used per pound of dried fuel	lbs.	*25·0*
56	Ratio of air used to air theoretically needed		*2·15*

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VI.—Trial of a Steam Plant at _____ Made on the _____ 19__

ENGINE. Sheet I. GENERAL DESCRIPTION AND DIMENSIONS.

Type of Engine { *Inverted-vertical triple-expansion surface-condensing.* } Made by { _____ }

Maker's rating of the power _____ I.HP. at _____ revolutions per minute and _____ lbs. per square inch, stop-valve pressure.

Test made at *74* I.HP., in the presence of . . . . . { _____ }

Character of load *Hydraulic Brake.*

Object of trial *Experimental research.*

Reference Number.	General description of engine.
88	*The engine was of the inverted cylinder type, with walls and covers separately jacketed. Each cylinder worked its own crank-shaft, having its own hydraulic brake; the revolutions of the shafts of the three cylinders were therefore not the same. Between the H.P. and I.P. and between the I.P. and L.P. were jacketed receivers, and the L.P. cylinder worked an air-pump off its crosshead.*
89	Type of Valves.—*Slide valves with Meyer expansion valves on the back for each cylinder; the cut-off can be varied by hand.*
90	How governed.—*A safety governor was arranged to entirely close the expansion valve if a certain predetermined speed was reached, but during the trial this speed was considerably above the average revolutions at which the three engines ran.*
91	Method of measuring steam consumption.—*By allowing the water from the hot well to escape into a 100-lb. tip-can.*

	Particulars of Cylinders:—		H.P.	I.P.	—	L.P.
92	Diameters of cylinders . . .	inches	*5·0*	*8·0*	..	*12·0*
	,, ,, piston-rods . .	,,	..	..	..	..
	Strokes of pistons	,,	*10·0*	*10·0*	..	*15·0*
93	Volumes swept by pistons per stroke (mean of two ends) .	c. ft.	*0·108*	*0·281*	..	*0·636*
94	Clearance volumes per stroke (mean of two ends) . . .	per cent.	*5·7*	*8·5*	..	*8·5*
95	Clearance surfaces per stroke (mean of two ends) . . .	sq. ft.	..	..	..	..
96	Proportion of clearance surfaces jacketed	per cent.	..	..	..	..
97	Proportion of barrel surfaces jacketed	,,	..	..	..	..
98	Receiver or reheater or interheater, volume of . . .	c. ft.	..	..	..	..
99	Receiver or reheater or interheater, heating surface of .	sq. ft.	..	..	..	..

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VII.—Trial of a Steam Plant at Made on the _____ 19___

ENGINE. Sheet II. DATA DEDUCED FROM OBSERVATIONS.

Reference Number.	Particulars of Observations.	—	Remarks.
100	Duration of trial . . . . . hours	4½	
101	Barometric pressure (atmosphere). } 29·59 ins. of mercury = lbs. per sq. in.	14·5	*By mercury barometer.*
	STEAM.		
102	Weight entering H.P. cylinder per hour . . . . . } lbs.	1054·8	
103	Weight passing through jackets per hour . . . . . } lbs.	158·4	
104	Pressure by gauge } at boiler side } lbs. per sq. in.	186·5	*Gauge tested before trial.*
	Pressure (absolute) } of stop valve }	201·0	
105	Temperature of steam at boiler side of stop valve . . . . } ° F.	382	
106	Moisture in steam at boiler side of stop valve. . . . } per lb.	*Nil.*	
107	Drainage from jackets per hour . lbs.	158·4	
108	Temperature of jacket drain water at exit from engine . } ° F.	382	
	EXHAUST STEAM.		
109	Pressure (absolute) at exit from engine . . . . . } lbs. per sq. in.	2·6	*Gauge tested before trial.*
110	Corresponding temperature of saturated steam . . . . . } ° F.	135	
111	Temperature at exit from engine. ° F.	135	*Mean pressures by ordinates.*
	POWER.		Corresponding—
112	Mean effective pressure in H.P. cylinder. . . . . } lbs. per sq. in.	75·56	I.HP. = 23·11
	Mean effective pressure in I.P. cylinder . . . . . } lbs. per sq. in.	29·81	,, = 23·86
	Mean effective pressure in L.P. cylinder. . . . . } lbs. per sq. in.	11·61	,, = 26·90
113	Mean pressures referred to L.P. cylinder. . . . . } lbs. per sq. in.		*Cards every ½ hour.*
114	Mean area of L.P. cylinder . sq. ins.		
115	Revolutions (by counter) . . per min.	*H.P. 322* *I.P. 320* *L.P. 276*	
116	Piston speed in L.P. cylinder in feet. . . . . } per min.		
117	I.HP. . . . . I.HP.	73·87	
118	B.HP. . . . . B.HP.	58·81	*Hydraulic brake for each cylinder.*
119	Mechanical efficiency = $\frac{\text{B.HP.}}{\text{I.HP.}}$ per cent.	79·6	

Cards were taken simultaneously off each end of the three cylinders, other observations at regular 10-minute intervals. The jacket steam drain was carried direct back to boiler, and a special device was used to measure the quantity which thus passed back.

NOTE.—Blank lines are left in this form for filling in observations which may be taken in engines using reheaters or interheaters, and for recording such observations as the temperature range in the cylinders, pressures in the jackets, and any other observations which it may be specially desired to record.

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VIII.—Trial of a Steam Plant at _____ Made on the _____ 19 .

ENGINE. Sheet III. HEAT ACCOUNT AND DEDUCTIONS.

Reference Number.	——	B.Th.U.	Per Cent.
	HEAT ACCOUNT (from 32° F.).		
120	Gross heat supply entering engine per minute	*24,223*	*100·0*
121	Heat equivalent of I.HP. . . . „	*3,133*	*12·94*
122	Heat leaving engine in jacket drain „	*924*	*3·82*
123	Heat leaving engine in exhaust steam . . . . . „	*19,011*	*78·49*
124	Balance of Heat Account (errors of observation, losses by radiation, etc).	*1,155*	*4·77*
	DEDUCTIONS (reckoned from exhaust temperature).		
125	Heat supplied per minute per I.HP. . . . B.Th.U.		*300*
126	Thermal efficiency		*14·14*
127	Heat theoretically required per minute by the "Institution of Civil Engineers standard of comparison" per I.HP. (Rankine's cycle) . B.Th.U.		*160·6*
128	Efficiency ratio		*53·5*
129	Heat supplied per minute per B.HP. . . . B.Th.U.		*377*
130	Pounds of steam used per I.HP. per hour . . . lbs.		*16·4*

REMARKS: _____

NOTE.—In engines using reheaters, interheaters, etc., the heat returned from them to the boiler should be entered in the heat balance on the "out"-side.

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IX.—Trial of a Steam Plant at Made on the 19

ENGINE ACCESSORIES. Sheet I. GENERAL DESCRIPTION AND DIMENSIONS.

Reference Number.		
	CONDENSER.	
131	General description of condenser. *Surface condenser of the torpedo boat type made of thin copper, 14 inches in diameter and 4 feet long. The exhaust pipe entering it being 8 inches in diameter.*	
	FOR SURFACE CONDENSER.	
132	Number of tubes	..
133	External diameter of tubes . . . . . inches	..
134	Length of tubes between tube-plates . . . . . feet	..
135	Effective area of cooling surface . . . . . sq. ft.	*160*
	AIR PUMPS.	
136	General description and method of driving. *Vertical type, worked by side levers from the slide block of the L.P. cylinder, 9 inches in diameter and 4½ inches stroke, with a foot valve, piston valve and cover valve. It can be worked at any speed up to 400 revolutions a minute.*	
	CIRCULATING PUMPS.	
137	General description and method of driving. *None in use. The circulating water was drawn from an iron tank 20 feet by 10 feet at a height of 116 feet above the engine room floor, and after passing through the condenser it escaped to a large measuring tank over a calibrated weir.*	
	FEED HEATER.	
138	General description of feed heater, and of connections to exhaust pipe, feed pump, and boiler connections. *None in use.*	
139	Heating surface (if any) *None* sq. ft.	
	STEAM PIPES.	
140	General description of steam pipe arrangements and of methods of draining them, kind of covering, etc. *Pipes slope towards boiler.*	
141	Diameter of main steam pipe	
142	Length of main steam pipe	

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X.—Trial of a Steam Plant at _____ Made on the _____ 19__

ENGINE ACCESSORIES. Sheet II. DATA DEDUCED FROM OBSERVATIONS.

Reference Number.				Remarks.
	CONDENSER.			
143	Cooling water passing through condenser per hour	lbs.	*24,180*	*Measured over weir.*
144	Temperature of cooling water as it enters condenser	°F.	*52·3*	
145	Temperature of cooling water as it leaves condenser	°F.	*94·9*	
146	Exhaust steam entering condenser per hour	lbs.	*1054·8*	
147	Temperature of exhaust steam as it enters condenser	°F.	*135*	
148	Temperature of condensed steam as it leaves condenser	°F.	*132·5*	*Vacuum gauge tested before trial.*
149	Vacuum in condenser ($\frac{26}{}$ inches of mercury = lbs. per sq. in.		*1·75 (absolute)*	
	AIR PUMP.			
150	Effective volume displaced by air-pump bucket per minute	cubic feet.	*45·5*	
151	Indicator HP. absorbed in pump	I.HP.	*Not measured.*	
	CIRCULATING WATER-PUMP.			
152	Effective strokes per minute, or revolutions per minute if centrifugal		*None used.*	
153	Indicator HP. absorbed in the pump	I.HP.		
	NOTE.—If the pumps are driven by an independent engine, the records of the tests of this engine should be filled up in an engine sheet.			
	FEED HEATER. (Heating of feed by exhaust steam.)			
154	Temperature of feed into	°F.	*None used.*	
155	„ „ out of	°F.		
156	„ of exhaust steam	°F.		
	FEED PUMP.			
157	Temperature of feed passing through pump	°F.	*132·5*	
158	Steam used by feed pump (if separately driven)	lbs. per hour.	*Not measured.*	
	STEAM PIPES.			
159	Steam pressure (absolute) in boiler	lbs. per sq. in.	*203*	
160	Steam pressure (absolute) at engine stop valve	lbs. per sq. in.	*201*	
161	Temperature of steam at boiler or at superheater end of pipe	°F.	*383*	
162	Temperature of steam at engine stop valve	°F.	*382*	
163	Moisture in steam at exit from boiler	per lb.	*Nil.*	
164	Moisture in steam at engine stop valve	per lb.	*Nil.*	
165	Water collected from steam-pipes per hour	lbs.	*Not weighed.*	

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I.—Trial of a Steam Plant at _____ Made on the _____ 19__

BOILER. Sheet I. GENERAL DESCRIPTION AND DIMENSIONS.

Type of Boiler *Water Tube.* Made by *Messrs. Babcock & Wilcox.*

Maker's rating of the output of the Boiler *10,000* lbs. of steam per hour.

Pressure for which designed *125* lbs. per square inch (gauge).

Test made at an output of *7,000* lbs. of steam per hour, at a pressure of *125* lbs. per sq. inch (gauge) in the presence of . . . . . .

Object of Trial *Contract conditions.*

Reference Number.	GENERAL DESCRIPTION OF BOILER AND LEADING DIMENSIONS.
1	*Ordinary Babcock & Wilcox type. Tubes, number 180, diameter 4 inches, length 15·67 feet, slope to horizontal 15°, horizontal rows staggered vertically. Steam drums, number 4, diameter 30 inches, length 16 feet. Mud drums, number 1, diameter 14 inches, length 12 feet. Rear connecting tubes, number 20, diameter 4 inches, length 4 feet. Water space, 406 cubic feet; steam space, 157 cubic feet.*
2	Method of starting and stopping the test *The trial was a continuous day's run under ordinary conditions; the condition of the fire at the end was approximately the same as at the start.*
3	Method of stoking and average thickness of fire *Hand firing, by regular staff of firemen.*
4	Production of draught *Natural.*
5	Chimney, height *above grate 101* ft. Area at bottom *12·57* sq. ft.; top *12·57* sq. ft.
6	Total grate surface (excluding dead plate) . . . sq. ft. *72*
7	Percentage of grate area occupied by air spaces between bars *50*
8	Total effective heating surface (steam drums *251·3* sq. ft, tubes *3037·5* sq. ft.) . . . . . sq. ft. *3288·8*
9	Capacity of water space . . at *half glass* c. ft. *406*
10	„ „ steam space . . inches in gauge „ *157* Area of water surface in boiler glass. sq. ft.

Boiler was in thoroughly good order, all brickwork had been recently overhauled, it was cleaned, and had been 10 days under steam before test began, flues were blown regularly at 10 a.m. and 10 p.m. each day. The heating surface was 45·7 times the grate area, and the grate area was 4·9 times the area of the smoke outlet into chimney.

NOTE.—Though most of the important figures on pages 304-314 are taken from actual trials, many of them are imaginary, introduced in order to show a set of forms completely filled up.

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II.—Trial of a Steam Plant at _____ Made on the _____ 19___

BOILER. Sheet II. DATA DEDUCED FROM OBSERVATIONS.

Reference Number.	Particulars of Observations.	—	Remarks.
12	Duration of trial . . . . . hours	*144*	
	FUEL.		
13	Short description	*Linden "Lump"*	*West Virginian Bituminous.*
14	Fired per hour . . . . . lbs.	*956*	
15	Analysis by weight of dried fuel, Carbon . . per cent.	*79·7*	
	" " " Hydrogen . "	*4·9*	
	" " " Sulphur . . "	*1·0*	*Special analysis.*
	" " " Ash . . . "	*4·1*	
	" " " Oxygen . . " / Other matters "	*10·3*	
16	Moisture in fuel as fired . . . . . per lb.	*0·03*	
17	Calorific value of dried fuel . . . . B.Th.U. per lb.	*14,240*	*By Bomb calorimeter.*
18	Carbon value per lb. of dried fuel	*0·98*	
	ASH AND CLINKER.		
19	Total per hour . . . . . lbs.	*71·2*	*7·44* per cent. of total fuel fired.
20	Carbonaceous matter in ash per hour . . . . lbs.	*45·0*	
	FLUE GASES.	By Vol. / By Weight.	
21	Analysis of dry flue gases, Carbonic Acid . . per cent.	*8·3* / *12·3*	
	" " " Carbonic Oxide . "	*0·0* / *0·0*	
	" " " Oxygen . . . . "	*11·4* / *12·2*	
	" " " Nitrogen, by difference "	*80·3* / *75·5*	
22	Average temperature leaving boiler flues . . . ° F.	*583*	
23	Mean specific heat of products of combustion . B.Th.U.	*0·242*	
	AIR AND DRAUGHT.		
24	Temperature of outside air . . . . . ° F.	*30°*	
25	Barometric pressure (*29·22* inches mercury) lbs. per sq. in.	*14·33*	
26	Pressure in ash-pit (if forced air-supply) inches of water	..	
27	" over fire . . . . . " "	..	
28	Draught at gas exit from boiler . . . " "	..	
29	" base of chimney . . . . " "	*+ 0·29*	
30	Weight of steam per hour used in producing draught lbs.	..	
	FEED WATER.		
31	From pump, economiser or feed heater per hour . lbs.	*7,496*	
32	Temperature of feed to boiler . . . . . ° F.	*208*	
	STEAM.		
33	Gauge pressure . . . . . lbs. per sq. in.	*124·8*	
34	Absolute pressure . . . . . " " "	*139·1*	
35	Total moisture in steam . . . . . per lb.	*0·009*	*By separator.*
36	Temperature of saturation . . . . . ° F.	*352°*	

Gas samples were collected every half hour, about 10 minutes being occupied in the work of collecting. All other observations were also taken half hourly, every gauge and thermometer was carefully checked before and after the trial. The coal was weighed out in 2 cwt. bags, and the feed measured by a pair of tanks.

NOTE.—When jacket condensed steam and reheater condensed steam are returned direct t
he boiler, the weight of each, returned per hour, should, if possible, be determined, and also th
emperatures at which they enter the boiler. The blank lines are intended for use in such case
ad for any other observations which it may be desired to record.

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III.—Trial of a Steam Plant at Made on the 19

BOILER. Sheet III. HEAT ACCOUNT AND DEDUCTIONS.

Reference Number.		B.Th.U.	Per Cent.
	HEAT ACCOUNT (per lb. of dried fuel).		
37	Total heat value of 1 lb. of dried fuel . . .	*14,240*	*100·0*
38	Heat transferred to the water (*thermal efficiency*)	*8,514*	*59·80*
39	Heat carried away by products of combustion .	*1,647*	*11·57*
40	Heat carried away by excess air	*1,703*	*11·96*
41	Heat lost in evaporating and in superheating moisture mixed with fuel	*39*	*0·27*
42	Heat lost by incomplete combustion	..	..
43	Heat lost by unburnt carbon in ash	*705*	*4·95*
44	Balance of heat account. Errors of observation, and unmeasured losses, such as—those due to radiation, escape of unburnt hydrocarbons, superheating moisture in air, loss in hot ashes, etc.	*1,632*	*11·45*
	Total . .	*14·240*	*100·0*
	DEDUCTIONS.		
45	Heat transmitted per square foot of heating surface per hour	B.Th.U.	*2400*
46	Weight of fuel fired per square foot of grate per hour	lbs.	*13·28*
47	Weight of dried fuel fired per square foot of grate per hour	lbs.	*12·88*
48	Water evaporated per lb. of fuel as fired . .	lbs.	*7·77*
49	Equivalent evaporation from and at 212° F. per lb. of fuel as fired	lbs.	*8·15*
50	Water evaporated per lb. of dried fuel . . .	lbs.	*8·04*
51	Equivalent evaporation from and at 212° F. per lb. of dried fuel	lbs.	*8·43*
52	Equivalent evaporation per lb. of carbon value of dried fuel from and at 212° F.	lbs.	*8·60*
53	Weight of feed, from and at 212° F., per square foot of heating surface per hour	lbs.	*2·37*
54	Velocity of steam leaving water surface. . .	feet per second.	..
55	Air used per lb. of dried fuel	lbs.	*23·35*
56	Ratio of air used to air theoretically needed		*2·14*

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IV.—Trial of a Steam Plant at __ Made on the____ 19

ECONOMISER AND SUPERHEATER. Sheet I.

General Description and Dimensions.

Reference Number.	
	Economiser.
57	General description of Economiser, and arrangement of flues, &c. *Ordinary Standard form, containing 192 pipes, deflectors are used to guide gas currents.*
58	Heating surface of economiser . . . . . *1,800* sq. feet.
	Superheater.
59	General description of superheater and of method of heating it. *A nest of U tubes, placed where hottest gases from flue impinge on them, and hung from bottom of a box with partition in centre to cause steam to circulate up and down tubes.*
60	Heating surface . . . . . *400* sq. feet.

Data Deduced From Observations.

	Economiser. (Heating of feed by flue gases.)	Abstract of Observations.	Remarks.
61[1]	Weight of feed water entering economiser per hour . lbs.	*7,590*	*Economiser leak is 94 lbs. of water per hour, determined by test after trial.*
62	Temperature of feed into . °F.	*117*	
63	,, ,, out of °F.	*208*	
64	,, of flue gases into °F.	*500*	
65	,, ,, ,, out of °F.	*310*	
	Analysis of dry flue gases leaving economiser—	By volume / By weight	
66	Carbonic acid . . per cent.	*7·9* / *10·6*	
	Carbonic oxide . . ,,	*0·0* / *0·0*	
	Oxygen . . . . ,,	*11·5* / *11·2*	
	Nitrogen (by difference) ,,	*80·6* / *78·2*	
67	Mean specific heat of flue gases leaving economiser . B.Th.U.	*0·241*	
	Superheater.		
68	Weight of steam entering superheater per hour . . . lbs.	*7,496*	
69	Steam pressure (absolute) into. lbs. per sq. inch.	*139*	
70	Moisture of steam into . per lb.	*0·009*	
71	Temperature of steam into °F.	*352*	
72	,, ,, out of °F.	*400*	
73	,, of flue gases into °F.	*583*	
74	,, ,, ,, out of °F.	*505*	
	Analysis of dry flue gases leaving superheater—	By volume / By weight	
75	Carbonic acid . . per cent.	*8·3* / *12·3*	
	Carbonic oxide . . ,,	*0·0* / *0·0*	
	Oxygen . . . . ,,	*11·4* / *12·2*	
	Nitrogen (by difference) ,,	*80·3* / *75·5*	
76	Mean specific heat of flue gases out of . . . . . B.Th.U.	*0·242*	

[1] *The feed water was measured by a couple of tanks. The ordinary suctio to the hot well of condenser was blanked off. The feed also passed through a mete as check.*

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V.—Trial of a Steam Plant at ___ _ _ _Made on the _ _ _ _19 _

ECONOMISER AND SUPERHEATER. Sheet II.

HEAT ACCOUNT AND DEDUCTIONS.

Reference Number.	HEAT ACCOUNT (per lb. of dried fuel).	B.Th.U.	Per Cent.
	ECONOMISER.		
77	Heat received from boiler flues, in gases and steam, per lb. of dried fuel (reckoned from air temperature)	2,848 [1]	100·0
78	Heat transferred to the water (*efficiency of economiser*)	745	26·16
79	Heat carried off in the chimney gases . .	1,885	66·20
80	Balance of heat account, including errors of observation and difference of heat contained in brickwork at beginning and end of tests, etc.	218	7·64
	Total . .	2,848	100·0
	SUPERHEATER.[2]		
81	Heat received from flue gases and steam per lb. of dried fuel (reckoned from air temperature)	3,350	100
82	Heat transferred to steam (*efficiency of superheater*)	249	7·43
83	Heat carried off in the chimney gases . .	2,878	85·91
84	Balance of heat account, including errors of observation, etc.	223	6·66
	Total . .	3,350	100·0
	DEDUCTIONS.		
85	Heat transmitted per square foot of heating surface of economiser per hour. . . .	B.Th.U.	384
86	Heat transmitted per square foot of heating surface of superheater per hour . . .	B.Th.U.	577
87	Efficiency of boiler, economiser, and superheater combined	per cent.	66·8

[1] *There is a loss of 30 B.Th.U. between superheater and economiser, owing to gases falling 5° in temperature from radiation loss.*

[2] If separately fired, enter results on boiler form.

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VI.—Trial of a Steam Plant at _____ Made on the _____ 19 _

ENGINE. Sheet I. General Description and Dimensions.

Type of Engine { *Horizontal triple expansion.* } Made by { _____ }

Maker's rating of the power _____ I.HP. at _____ revolutions per minute and _____ lbs. per square inch, stop-valve pressure.

Test made at _____ HP., in the presence of . . . { _____ _____ _____ _____ }

Character of load *Pumping water.*

Object of trial *Contract guarantee.*

Reference Number.						
88	General description of engine.—*Horizontal, three crank, cranks 120° apart in sequence high, low, intermediate; reheating-receivers are placed between first and second and between second and third cylinders. Both barrels and heads of all three cylinders are jacketed. A feed-heater is interposed between third cylinder and condenser.*					
89	Type of valves.—*Corliss placed in main cylinder casting.*					
90	How governed.—*The governor controls cut-off in HP. cylinder, the cut-off in the other two cylinders is varied by hand.*					
91	Method of measuring steam consumption.—*Feed to boiler was measured, as there were no leakages this was taken as equal to weight of steam supplied to engine.*					
	Particulars of cylinders :—		HP.	I.P.	—	L.P.
92	Diameters of cylinders . . .	inches	*21*	*37*		*55*
	,, ,, piston-rods . .	,,	*3·63*	*3·63*		*3·63*
	Stroke of pistons	,,	*47·97*	*47·95*		*47·94*
93	Volumes swept by pistons per stroke (mean of two ends) .	c. ft.	*9·3*	*29·55*		*65·62*
94	Clearance volumes per stroke (mean of two ends) . . .	per cent.	*1·75*	*1·75*		*2·13*
95	Clearance surfaces per stroke (mean of two ends) . . .	sq. ft.	*Not measured.*			
96	Proportion of clearance surfaces jacketed	per cent.	,,	,,		
97	Proportion of barrel surfaces jacketed	,,	,,	,,		
98	Receiver or reheater or interheater, volume of	c. ft.	*22·84*		*47·82*	
99	Receiver or reheater or interheater, heating surface of .	sq. ft.	*88·0*		*166·9*	

The first reheater was 30 inches diameter, 55 inches high, connected by a 7-inch pipe 8·73 feet long to HP. cylinder, and by a 9-inch pipe 4·65 feet long to I.P. cylinder. The second reheater was 42 inches diameter, 60 inches high, connected by a 12-inch pipe 5·38 feet long to I.P. cylinder, and by a 12-inch pipe 3·53 feet long to L.P. cylinder. Exhaust to feed heater was a 16-inch pipe 8·85 feet long.

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VII.—Trial of a Steam Plant at Made on the _____ 19 _

ENGINE. Sheet II. DATA DEDUCED FROM OBSERVATIONS.

Reference Number.	Particulars of Observations.	—	Remarks.
100	Duration of trial . . . . . hours	21	
101	Barometric pressure (atmosphere) $\frac{29{\cdot}15}{}$ inches of mercury = lbs. per sq. inch.	14·29	
	STEAM.		
102	Weight entering HP. cylinder per hour . . . . . lbs.	6,417	It was not possible to separately weigh Jacket and Reheater condensed steam.
103	Weight passing through jackets per hour . . . . . lbs.	1,079	
104	Pressure by gauge at boiler side / Pressure (absolute) of stop valve lbs. per sq. in.	124·8 / 139·1	
105	Temperature of steam at boiler side of stop valve . . . . . °F.	395	
106	Moisture in steam at boiler side of stop valve . . . . . per lb.	0·0	A leakage of 9 lbs. an hour was caught and weighed.
107	Drainage from jackets per hour . lbs.	1,070	
108	Temperature of jacket drain water at exit from engine . . . . . °F.	350°	
	EXHAUST STEAM.		
109	Pressure (absolute) at exit from engine . . . . . lbs. per sq. in.	1·82	
110	Corresponding temperature of saturated steam . . . . . °F.	120	
111	Temperature at exit from engine. °F.	119·1	
	POWER.		Corresponding—
112	Mean effective pressure in HP. cylinder . . . . . lbs. per sq. in.	46·17	I.HP. = 196
	Mean effective pressure in I.P. cylinder . . . . . lbs. per sq. in.	14·88	,, = 129·2
	Mean effective pressure in L.P. cylinder . . . . lbs. per sq. in.	8·94	,, = 199·1
113	Mean pressures referred to L.P. cylinder . . . . . lbs. per. sq. in.	22·22	
114	Mean area of L.P. cylinder . sq. in.	2,365	
115	Revolutions (by counter) . . per min.	38·84	
116	Piston speed in L.P. cylinder in feet . . . . . per min.	310	
117	Indicator horse power . . . I.HP.	494·3	
118	Brake horse power . . . . B.HP.	..	
119	Mechanical efficiency = $\frac{\text{B.HP.}}{\text{I.HP.}}$ per cent.	..	

For the test, steam for Jackets and Reheaters was led from a special connection to steam-pipe (instead of ordinary connection through separator drip-pipe) and all condensed steam from them was collected and weighed in one lot.

NOTE.—Blank lines are left in this form for filling in observations which may be taken in engines using reheaters or interheaters, and for recording such observations as the temperature range in the cylinders, pressures in the jackets, and any other observations which it may be specially desired to record.

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VIII.—Trial of a Steam Plant at _____ Made on the _____ 19__

ENGINE. Sheet III. HEAT ACCOUNT AND DEDUCTIONS.

Reference Number.		B.Th.U.	Per Cent.
	HEAT ACCOUNT (from 32° F.).		
120	Gross heat supply entering engine per minute	*129,300*	*100*
121	Heat equivalent of indicator horse power . . . . . „ „	*20,970*	*16·23*
122	Heat leaving engine in jacket drain . . . . . „ „	*5,671*	*4·39*
123	Heat leaving engine in exhaust steam . . . . . „ „	*91,346*	*70·66*
124	Balance of Heat Account (errors of observation, losses by radiation, etc.	*11,313*	*8·72*
	DEDUCTIONS (reckoned from exhaust temperature).		
125	Heat supplied per minute per I.HP. . . . B.Th.U.		*283*
126	Thermal efficiency		*15·0*
127	Heat theoretically required per minute by the "Institution of Civil Engineers standard of comparison" per I.HP. (Rankine's cycle) . B.Th.U.		*163*
128	Efficiency ratio		*0·576*
129	Heat supplied per minute per B.HP. . . . B.Th.U.		..
130	Pounds of steam used per I.HP. per hour . . . lbs.		*15·17*

REMARKS: *Every instrument used on the trial was carefully calibrated after the trials were over, and all observations were taken simultaneously at half-hourly intervals.*

NOTE.—In engines using reheaters, interheaters, etc., the heat returned from them to the boiler should be entered in the heat balance on the "out"-side.

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IX.—Trial of a Steam Plant at _____ Made on the _____ 19 __

ENGINE ACCESSORIES. Sheet I. GENERAL DESCRIPTION AND DIMENSIONS.

Reference Number.	
	CONDENSER.
131	General description of condenser. *Jet, 28 inches diameter, 74 inches high; volume of steam space 24·05 cubic feet. Ratio of its volume to L.P. cylinder volume, 0·366. Diameter exhaust pipe, 16 inches; of injection-pipe, 5 inches from pump well.*
	FOR SURFACE CONDENSER.
132	Number of tubes . . . . .
133	External diameter of tubes . . . . . inches
134	Length of tubes between tube-plates. . . . . feet
135	Effective area of cooling surface . . . . . sq. ft.
	AIR PUMPS.
136	General description and method of driving. *Two single-acting, driven by main engine through a rocking-lever, 17 inches diameter, 18 inches stroke; bucket valves, each pump has 5; they are rubber disks 5¼ inches diameter; delivery valves, each pump has 6, rubber disks 6¼ inches diameter; there are no foot valves; discharge pipe, 10 inches diameter.*
	CIRCULATING PUMPS.
137	General description and method of driving.—*None in use.*
	FEED HEATER.
138	General description of feed heater, and of connections to exhaust pipe, feed pump, and boiler connections. *Diameter, 42 inches; 70 inches high; net steam volume, 32·3 cubic feet. Number of brass tubes, 357; each 1 inch external diameter and 50·5 inches long, connected by 16-inch pipe 8·85 feet long to L.P.-cylinder, and by 16-inch pipe 1·27 feet long to condenser, to which also a 2-inch drip-pipe from feed-heater passes.*
139	Heating surface (if any).—*Tubes, 393·3 sq. feet; total, 408·7* sq. ft.
	STEAM PIPES.
140	General description of steam-pipe arrangements and of methods of draining them, kind of covering, etc. *Steam from boiler passes through 41 feet of 8-inch, and then through 21 feet of 6-inch pipe; then it enters a separator 18 inches diameter, 24 inches high; from bottom of this a 6-inch pipe drops 4 feet 6 inches to throttle-valve, which is 9 inches above cylinder. The 8-inch pipe first rises 8 feet, and afterwards 10 inches; rest of it is horizontal; 6-inch pipe has 10 feet horizontal, and then a drop of 11 feet to separator. The separator has a 1-inch drain-pipe, which also conveys steam to cylinder Jackets and Reheaters, the whole drainage of which normally passes back direct to Boiler.*
141	Diameter of main steam pipe } *See under 140.*
142	Length of main steam pipe }

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X.—Trial of a Steam Plant at _____ Made on the _____ 19__

ENGINE ACCESSORIES. Sheet II. DATA DEDUCED FROM OBSERVATION

Reference Number.				Remarks.
	CONDENSER.			
143	Cooling water passing through condenser per hour	lbs.	87,300	*Measured by weir*
144	Temperature of cooling water as it enters condenser	°F.	33·20	
145	Temperature of cooling water as it leaves condenser	°F.	91·60	
146	Exhaust steam entering condenser per hour	lbs.	6,417	
147	Temperature of exhaust steam as it enters condenser	°F.	119·1	
148	Temperature of condensed steam as it leaves condenser	°F.	91·6	
149	Vacuum in condenser	$\frac{25·7}{}$ inches of mercury = lbs. per sq. in.	1·69	*Absolute*
	AIR PUMP.			
150	Effective volume displaced by air-pump bucket per minute	cubic feet.	91·8	*(For each pump.)*
151	Indicator HP. absorbed in pump	I.HP.	2·28	*(For two pumps.)*
	CIRCULATING WATER-PUMP.			
152	Effective strokes per minute, or revolutions per minute if centrifugal	. .		
153	Indicator HP. absorbed in the pump	I.HP.		
	NOTE.—If the pumps are driven by an independent engine, the records of the tests of this engine should be filled up in an engine sheet.			
	FEED HEATER. (Heating of feed by exhaust steam.)			
154	Temperature of feed into	°F.	33·7	
155	„ „ out of	°F.	117·8	
156	„ of exhaust steam	°F.	120·0	
	FEED PUMP.			
157	Temperature of feed passing through pump[1]	°F.	117·8	
158	Steam used by feed pump[1] (if separately driven)	lbs. per hour.	..	*The two pumps absorbed 3·6 HP. to drive them.*
	STEAM PIPES.			
159	Steam pressure (absolute) in boiler	lbs. per sq. in.	139·1	
160	Steam pressure (absolute) at engine stop valve	lbs. per sq. in.	139·1	
161	Temperature of steam at boiler or at superheater end of pipe	°F.	400	*At exit from superheater.*
162	Temperature of steam at engine stop valve	°F.	395	
163	Moisture in steam at exit from boiler	per lb.	0·009	*Before entering superheater.*
164	Moisture in steam at engine stop valve	per lb.	0·0	
165	Water collected from steam-pipes per hour	lbs.	0·0	

[1] *These were two feed pumps, each 4½ inches diameter and 8 inches stroke driven off an air-pump rocking-lever. The suction pipes were a common 4-inch pipe dividing into two 3-inch (one to each pump) similarly for discharge.*

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XI.—Trial of a Steam Plant at ___ Made on the ___19

SUMMARY.

Rated power of the Plant 750 I.HP.

Test made at ⅞ of the rated power, in the presence of

ECONOMY OF THE COMPLETE PLANT.

Reference Number.			
166	Total heat value of fuel fired in boiler and superheater per minute	B.Th.U.	220,150
167	Heat equivalent per minute of I HP. developed	,,	20,961
168	,, ,, ,, ,, B.HP.	,,	,,
169	Percentage of heat utilized in I.HP.	,, per cent.	9·53
170	,, ,, ,, B.HP.	,,	,,
171	Coal fired per I.HP. per hour	lbs.	1·93

REMARKS: *All pipes not in use were blanked off, and during a preliminary series of tests all leaks were, as far as possible, localised and stopped. All steam-piping was covered with 1 inch magnesia sectional covering. The cylinders were covered with plastic cement, hair felting and planished steel lagging, the heads having polished cast iron false covers. Reheaters, feed-heaters were covered with 2 inches of asbestos cement.*

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SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 3334.*)

"Tables of Formulas for Points and Crossings."

By EVELYN HENRY YOUNG, Assoc. M. Inst. C.E.

IN a recent Communication[1] to the Institution by Messrs. Preston and Barnard is given a method of calculating the leads of crossings, based on the principle of the "orbit circle," and designed to give curves tangential to both the switch and the crossing. Tangential curves are, of course, no new thing, but the method of calculation appears to be novel and distinctly superior to that which the Author has always employed. The formulas deduced by Messrs. Preston and Barnard do not, however, always give the results in the form in which they are required in actual practice. In the case of the main-line being curved, for instance, they give the lead as the length of a perpendicular from a point on to an imaginary line, and this kind of measurement is one in which an ordinary platelayer would be very likely to make a mistake. To ensure accuracy on his part, the lead given him must be one which he can only measure in the right way, and the best way to do this is to give him the measurement along the rail, *i.e.*, the arc of the curve when the main-line is curved. Moreover, to ensure the true laying of the turn-out curve the platelayer should be given its exact length, and then he can cut the rails exactly and avoid kinks in the curve. In the following Paper the Author deduces formulas which give the results in such a form that the measurements may be given to the platelayer without risk of error on his part. The formulas are collected in tabular form in the Appendix.

The following symbols are used throughout the Paper:—

g the gauge of the line.

d the distance between the running faces of the switch and the stock rail, at heel of switch.

δ the angle between the switch and the stock-rail

$$= \sin^{-1} \frac{d}{\text{length of switch}}.$$

[1] Minutes of Proceedings Inst. C.E., vol. cxlv. p. 245.

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a the angle of crossing.

r the radius of the centre line of the main-line curve.

L the lead, measured along the main-line rail from heel of switch to nose of crossing.

T the length of the turn-out curve, measured along the rail from heel of switch to nose of crossing.

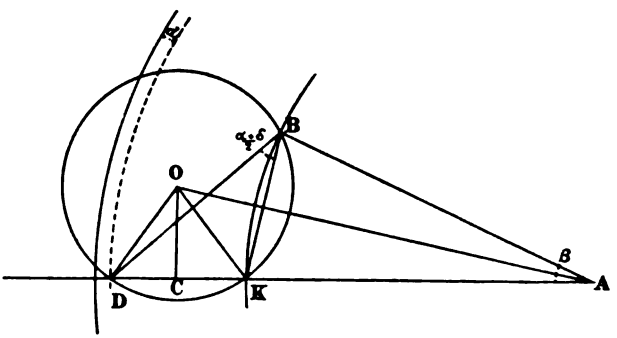
R the radius of the turn-out curve, measured to the rail on which the crossing lies.

To find the lead, measured along the main-line rail from heel of switch to nose of crossing:—

(*1*) *Main line curved, Crossing on inner rail of curve, Fig. 1.*

A is the centre of the main-line curve, D and K the heels of the switches, B the crossing. Let O be the centre of the orbit circle,

Fig. 1.



which, as shown by Messrs. Preston and Barnard, passes through D, B and K; and let O C be perpendicular to A D. Then, by the principle of the orbit circle—

$$\text{angle D B K} = \frac{a+\delta}{2}.$$

Also $$\text{D K} = g - d,$$

and $$\text{A C} = r - \frac{d}{2};$$

but $\frac{d}{2}$ is so small compared with r that it may be neglected; hence, practically—

$$\text{A C} = r,$$

and $$\text{L} = \text{arc B K}.$$

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Let angle B A K, subtended by the lead, be called β.

Then $$\text{angle K O C} = \text{angle D B K} = \frac{a+\delta}{2},$$

and $$\text{O C} = \text{C K} \cot \text{K O C} = \frac{g-d}{2} \cot \frac{a+\delta}{2}$$

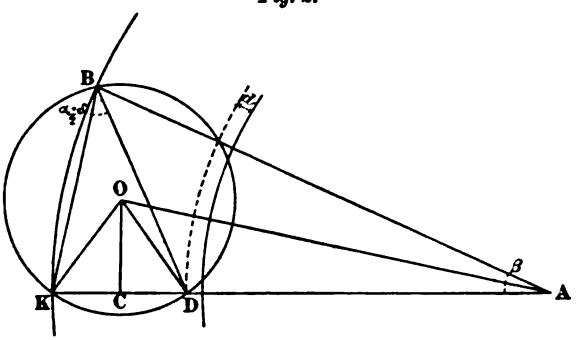
$$\beta = 2 \tan^{-1} \frac{\text{O C}}{\text{A C}} = 2 \tan^{-1} \left(\frac{g-d}{2r} \cot \frac{a+\delta}{2} \right). \quad (1)$$

$$\text{L} = \beta^* \times \text{A K}$$

$$= \beta \left(r - \frac{g}{2} \right). \quad (2)$$

(2) ***Main line curved, Crossing on outer rail of curve, Fig. 2.***

Fig. 2.



B will be the crossing,

and $$\text{A C} = r + \frac{d}{2}, \text{ or practically } r;$$

$$\text{L} = \text{arc B K}.$$

Then β remains as before,

and $$\text{L} = \beta \times \text{A K}$$

$$= \beta \left(r + \frac{g}{2} \right). \quad (3)$$

(3) ***Main line straight, Fig. 6.***

D K B becomes a right angle,

and $$\text{L} = (g-d) \cot \frac{a+\delta}{2} \quad (4)$$

* The angle being, of course, taken in radian measure.

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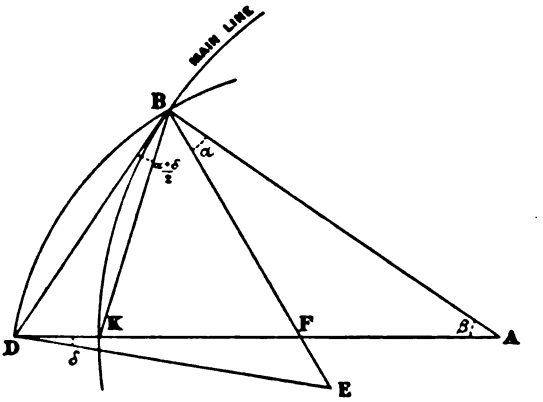
To find the radius and length of the turn-out curve:—

(1) *Main line curved, Crossing on inner rail of curve, Fig. 3.*

Fig. 3.



Let E be the centre of the turn-out curve.

Then—

angle A B E = α, angle A D E = δ, and angle D B K = $\frac{\alpha+\delta}{2}$,

$$A B = A K = r - \frac{g}{2}, \quad R = E B, \quad T = \text{arc } D B,$$

angle B E D = B F D − δ = $\alpha + \beta - \delta$,

angle B D A = $\left(\frac{\pi}{2} - \frac{\alpha+\beta-\delta}{2}\right) - \delta = \frac{\pi}{2} - \frac{\alpha+\beta+\delta}{2}$,

$$B D = A B \frac{\sin \beta}{\sin B D A},$$

$$= \left(r - \frac{g}{2}\right) \frac{\sin \beta}{\cos \frac{\alpha+\beta+\delta}{2}},$$

$$R = \frac{B D}{2} \operatorname{cosec} \frac{B E D}{2},$$

$$R = \frac{1}{2}\left(r - \frac{g}{2}\right) \frac{\sin \beta}{\sin \frac{\alpha+\beta-\delta}{2} \cos \frac{\alpha+\beta+\delta}{2}} \quad . \quad (5)$$

$$= \left(r - \frac{g}{2}\right) \frac{\sin \beta}{\sin (\alpha+\beta) - \sin \delta} \quad . \quad . \quad . \quad (5a)$$

$$T = (\alpha + \beta - \delta) \cdot R. \quad . \quad . \quad . \quad . \quad (6)$$

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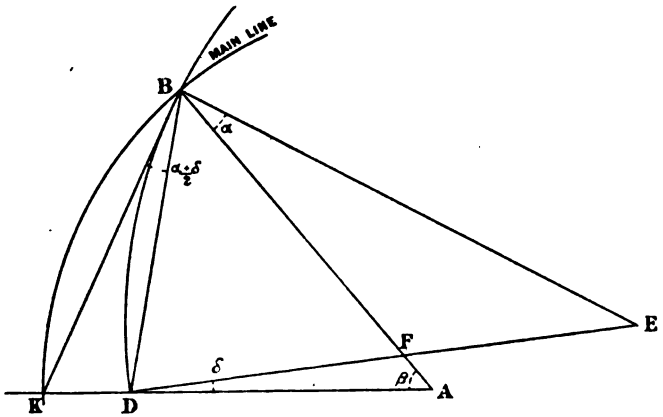
(2) *Main line curved, Crossing on outer rail of curve.*

(*a*) Turn-out and main-line curves of similar flexure, *Fig. 4.*

Fig. 4.



$$\text{angle B E D} = (\beta + \delta - \alpha). \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$R = \frac{1}{2}\left(r + \frac{g}{2}\right) \frac{\sin \beta}{\cos \frac{\alpha + \delta - \beta}{2} \sin \frac{\beta + \delta - \alpha}{2}} \quad . \quad (8)$$

$$= \left(r + \frac{g}{2}\right) \frac{\sin \beta}{\sin (\beta - \alpha) + \sin \delta} \quad . \quad . \quad . \quad . \quad (8a)$$

and $$T = (\beta + \delta - \alpha) R \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

(*b*) Turn-out and main-line curves of contrary flexure, *Fig. 5.*

$$\text{angle B E D} = (\alpha - \beta - \delta) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

$$R = \frac{1}{2}\left(r + \frac{g}{2}\right) \frac{\sin \beta}{\cos \frac{\alpha + \delta - \beta}{2} \sin \frac{\alpha - \beta - \delta}{2}} \quad . \quad (11)$$

$$= \left(r + \frac{g}{2}\right) \frac{\sin \beta}{\sin (\alpha - \beta) - \sin \delta} \quad . \quad . \quad . \quad . \quad (11a)$$

and $$T = (\alpha - \beta - \delta) R \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

In both cases $A B = r + \frac{g}{2}$, and $\text{angle B D A} = \frac{\pi}{2} + \frac{\alpha + \delta - \beta}{2}$.

Equations (7) and (10) may be written—

$$\text{angle B E D} = \pm (\beta - (\alpha - \delta)),$$

the + or − sign being taken according as the curves are of similar or contrary flexure; but as the angle itself is a positive

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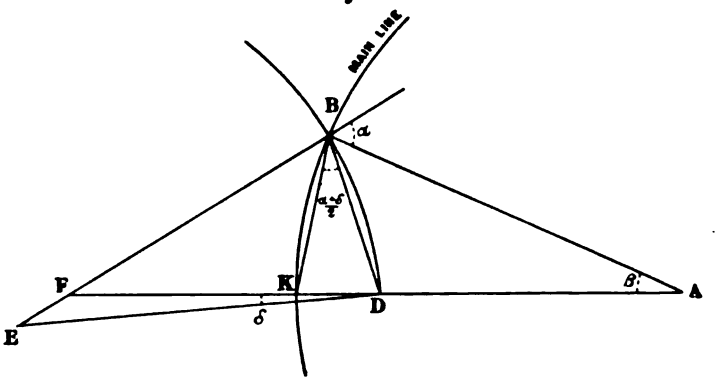
quantity in each case, it follows that the curves must be of similar or contrary flexure, according as β is greater or less than $(\alpha - \delta)$. Thus as soon as β is found it becomes apparent whether the proposed flexures of the two curves are possible or not. If $\beta = \alpha - \delta$ the turn-out will be straight. This is a very useful check.

Fig. 5.



If the straight lead with the given crossing, etc., is known, formula (1) may be simplified. Let the straight lead be called L_s, then, by combining equations (1) and (4),

$$\beta = 2 \tan^{-1} \frac{L_s}{2r} \quad . \quad . \quad . \quad . \quad (13)$$

(3) *Main line straight, Fig. 6.*

$$\text{angle B F D} = \alpha, \text{ angle B E D} = \alpha - \delta,$$

$$\text{B D} = \text{D K} \operatorname{cosec} \frac{\alpha + \delta}{2} = (g - d) \operatorname{cosec} \frac{\alpha + \delta}{2},$$

$$\text{R} = \frac{\text{B D}}{2} \operatorname{cosec} \frac{\text{B E D}}{2},$$

$$\text{R} = \frac{g - d}{2 \sin \frac{\alpha + \delta}{2} \sin \frac{\alpha - \delta}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

$$= \frac{g - d}{\cos \delta - \cos \alpha} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14a)$$

$$\text{T} = (\alpha - \delta) \text{ R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

Formulas (14) and (14*a*) are, of course, the same as those given by Messrs. Preston and Barnard and by Mr. W. H. Cole.[1]

[1] "Permanent-way Material, etc." By W. H. Cole, M. Inst. C.E., p. 96. London, 1900 (third edition).

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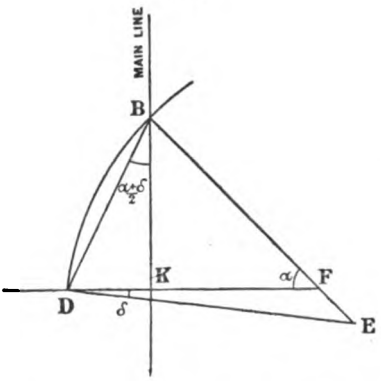
It is a convenient check on correct laying to know the middle offset of the turn-out curve. This is given in each case by the formula—

$$\text{mid. offset} = \text{R vers} \frac{\text{B E D}}{2} \quad . \quad . \quad . \quad . \quad . \quad (16)$$

where B E D has the values $(\alpha + \beta - \delta)$, $(\beta + \delta - \alpha)$, $(\alpha - \beta - \delta)$ and $(\alpha - \delta)$ in the four successive cases considered in the foregoing.

If the curves of both lines are given, and it is desired to find the necessary crossing, this can be found from formulas (5), (8), (11) and (14) of Messrs. Preston and Barnard's Paper, and these formulas therefore are included in the Tables, with only the necessary alterations to introduce the symbols used by the Author, *i.e.*, making r and r_1 the radii of the centre-lines of the tracks, instead of the radii of the actual rails.

Fig. 6.



In most cases what is really required is not the exact theoretical angle of crossing to suit the data, but to find which of the available standard crossings of the line is the nearest to the theoretical angle, and for this purpose a sufficiently close approximation will usually be given by assuming the curve of the turn-out to be continued through the switch. Then d and δ both vanish, and the formulas for cos α take the simplified forms given in the Appendix, in the last column of Table V.

The Paper is accompanied by a sheet of tracings, from which the Figures in the text have been prepared, and by the following Appendix.

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APPENDIX.

Tables of Formulas for Calculating Leads and Angles of Crossings.

In these Tables the following symbols are used throughout:—

g the gauge of the line.

d the distance between the running faces of the switch and the stock rail, at heel of switch.

δ the angle between the switch and the stock rail $= \sin^{-1} \frac{d}{\text{length of switch}}$.

α the angle of crossing.

r the radius of the centre line of the main-line curve.

R the radius of the turn-out curve measured to the rail on which the crossing lies.

L_s the lead, measured along the main-line rail from heel of switch to nose of crossing, when the main line is straight.

L_c the lead, similarly measured, when the main line is curved.

T the length of the turn-out curve, measured along the rail, from heel of switch to nose of crossing.

Table I.—Main Line Straight.

To find lead, etc., with given crossing and switch.

Lead L_s	$(g-d) \cot \frac{\alpha+\delta}{2}$
Radius R	$\frac{g-d}{\cos\delta-\cos\alpha}$ *or* $\frac{g-d}{2\sin\frac{\alpha+\delta}{2}\sin\frac{\alpha-\delta}{2}}$
Length of curve T	$(\alpha-\delta)^*$. R
Middle offset of T	$R \cdot \text{vers}\frac{\alpha-\delta}{2}$

* In this and similar formulas the angle must, of course, be taken in radian measure.

Table II.—Main Line Curved and Crossing on Inner Rail of Curve.

To find lead, etc., with given crossing and switch.

β	$2\tan^{-1}\left(\frac{g-d}{2r}\cot\frac{\alpha+\delta}{2}\right)$ *or* $2\tan^{-1}\frac{L_c}{2r}$
Lead L_c . . .	$\beta \cdot \left(r-\frac{g}{2}\right)$
Radius R . .	$\left(r-\frac{g}{2}\right)\frac{\sin\beta}{\sin(\alpha+\beta)-\sin\delta}$ *or* $\left(r-\frac{g}{2}\right)\frac{\sin\beta}{2\sin\frac{\alpha+\beta-\delta}{2}\cos\frac{\alpha+\beta+\delta}{2}}$
Length of curve T	$(\alpha+\beta-\delta)$. R
Middle offset of T	$R \cdot \text{vers}\frac{\alpha+\beta-\delta}{2}$

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TABLE III.—MAIN LINE CURVED AND CROSSING ON OUTER RAIL OF CURVE. CURVES OF MAIN LINE AND TURN-OUT OF SIMILAR FLEXURE.

To find lead, etc., with given crossing and switch.

β^*	$2\tan^{-1}\left(\frac{g-d}{2r}\cot\frac{\alpha+\delta}{2}\right)$ *or* $\tan^{-1}\frac{L_c}{2r}$
Lead L_c . . .	$\beta\cdot\left(r+\frac{g}{2}\right)$
Radius R . .	$\left(r+\frac{g}{2}\right)\frac{\sin\beta}{\sin(\beta-\alpha)+\sin\delta}$ *or* $\left(r+\frac{g}{2}\right)\frac{\sin\beta}{2\sin\frac{\beta+\delta-\alpha}{2}\cos\frac{\beta-\alpha-\delta}{2}}$
Length of curve T	$(\beta+\delta-\alpha)\ .\ R$
Middle offset of T	$R\cdot\operatorname{vers}\frac{\beta+\delta-\alpha}{2}$

* If β is less than $(\alpha-\delta)$ this combination is impossible, and the curves must be of contrary flexure. If $\beta=\alpha-\delta$ the turn-out is straight.

TABLE IV.—MAIN LINE CURVED AND CROSSING ON OUTER RAIL OF CURVE. CURVES OF MAIN LINE AND TURN-OUT OF CONTRARY FLEXURE.

To find lead, etc., with given switch and crossing.

β^*	$2\tan^{-1}\left(\frac{g-d}{2r}\cot\frac{+\delta}{2}\right)$ *or* $2\tan^{-1}\frac{L_c}{2r}$
Lead L_c . . .	$\beta\cdot\left(r+\frac{g}{2}\right)$
Radius R . .	$\left(r+\frac{g}{2}\right)\frac{\sin\beta}{\sin(\alpha-\beta)-\sin\delta}$ *or* $\left(r+\frac{g}{2}\right)\frac{\sin\beta}{2\sin\frac{\alpha-\beta-\delta}{2}\cos\frac{\alpha-\beta+\delta}{2}}$
Length of curve T	$(\alpha-\beta-\delta)\ .\ R$
Middle offset of T	$R\cdot\operatorname{vers}\frac{\alpha-\beta-\delta}{2}$

* If β is greater than $(\alpha-\delta)$ this combination is impossible, and the curves must be of similar flexure. If $\beta=\alpha-\delta$ the turn-out is straight.

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TABLE V.—GIVEN THE CURVES OF MAIN LINE AND TURN-OUT, TO FIND THE CROSSING REQUIRED.

r = radius of centre line of main-line curve.
r_1 = " " " turn-out curve.

Main line.	Crossing on Inner or Outer Rail.	Flexure of Curves.	Value of cos α. Exact.	Value of cos α. Approximate.
Straight	..	..	$\cos\delta - \frac{g-d}{r_1+g}$	$\frac{r_1-\frac{g}{2}}{r_1+\frac{g}{2}}$
Curved	Inner	Similar	$\frac{r+\frac{g}{2}-d}{r-\frac{g}{2}}\cos\delta - \frac{(g-d)\left(r+\frac{d}{2}\right)}{\left(r-\frac{g}{2}\right)\left(r_1+\frac{g}{2}\right)}$	$\frac{r+\frac{g}{2}}{r-\frac{g}{2}} - \frac{g\,r}{\left(r-\frac{g}{2}\right)\left(r_1+2\right)}$
Curved	Outer	Similar	$\frac{r-\frac{g}{2}+d}{r+\frac{g}{2}}\cos\delta + \frac{(g-d)\left(r+\frac{d}{2}\right)}{\left(r+\frac{g}{2}\right)\left(r_1-\frac{g}{2}\right)}$	$\frac{r-\frac{g}{2}}{r+\frac{g}{2}} + \frac{g\,r}{\left(r+\frac{g}{2}\right)\left(r_1-\frac{g}{2}\right)}$
Curved	Outer	Contrary	$\frac{r-\frac{g}{2}+d}{r+\frac{g}{2}}\cos\delta - \frac{(g-d)\left(r+\frac{d}{2}\right)}{\left(r+\frac{g}{2}\right)\left(r_1+\frac{g}{2}\right)}$	$\frac{r-\frac{g}{2}}{r+\frac{g}{2}} - \frac{g\,r}{\left(r+\frac{g}{2}\right)\left(r_1+\frac{g}{2}\right)}$

Values of α and cos α for some crossings are given in the following Table:—
If the crossing is 1 in n, then n = cot α.

Crossing.	α. °	′	″	cos α.	Crossing.	α. °	′	″	cos α.
1 in 5	11	18	36	0·9805805	1 in 10	5	42	38	0·9950372
1 „ 5·03	11	15		0·9807853	1 „ 10·38	5	30		0·9953962
1 „ 6	9	27	44	0·9863942	1 „ 12	4	45	49	0·9965459
1 „ 6·14	9	15		0·9869964	1 „ 12·03	4	45		0·9965655
1 „ 7	8	7	49	0·9899491	1 „ 15	3	48	51	0·9977850
1 „ 7·35	7	45		0·9908659	1 „ 15·25	3	45		0·9978589
1 „ 8·45	6	45		0·9930685	1 „ 17·61	3	15		0·9983917
1 „ 8½	6	42	35	0·9931706	1 „ 19·08	3	0		0·9986295

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(*Paper No. 3342.*)

"Federated Malay States Railways, Perak and Province Wellesley."

By CHARLES RASTRICK HANSON, M. Inst. C.E.

PREVIOUS to the opening of the Larut Railway, in the State of Perak, the principal port in the north of the State was Teluk Kertang, on the Larut River, which was connected, by a metalled cart-road about 6 miles in length, with Taiping, the chief town of the State, Fig. 1, Plate 9. Frequent outbreaks of cattle disease, causing interruptions to cart traffic, demonstrated the necessity for a more reliable means of transport between the port and the mining district of Larut than was afforded by bullock-carts. In 1884 a railway came to be looked upon as a requirement which could no longer be dispensed with, and construction was commenced as soon as a suitable position for a new port, easier of access than Teluk Kertang, was determined upon. The Larut Railway, 8¼ miles in length, from Port Weld, on the Sapetang River, to Taiping, was opened for traffic in 1885, and has proved a financial success, earning between 6 per cent. and 10 per cent. per annum on the capital expenditure, after deducting the cost of working and maintenance; it was extended in a northerly direction for a distance of 8¾ miles in 1889–1890.

In May 1891, the construction of the Kinta Valley Railway, a line 50 miles in length, was commenced. The construction of this line from the port of Teluk Anson on the Perak River, in the south of the State, through the district of Lower Perak, Batang Padang and Kinta, to Ipoh, the principal town of the Kinta district, was undertaken with the same object as that in the Larut district, namely, to cheapen the cost of transport to the mining districts of Perak, to obviate the inconvenience caused by periodical interruptions to cart transport, and to aid in the general development of the State. Until this line was opened for traffic, all supplies for the mining district of Kinta were conveyed from the port by the laborious poling of flat-bottomed boats up the Kinta River (a journey occupying 6 days to a fortnight), to

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villages on the river-bank, whence they were carted to the trade centres and mines; goods had sometimes to be unloaded on the banks of the river, as in dry seasons boats could only ascend the higher reaches of the river with half-loads. Consequently there was always great uncertainty as to when a cargo would reach its destination, as well as risk of damage and loss. This line also proved a financial success. It was opened in sections, as these were completed, the final section being opened in May, 1895; the profit earned on the first year's working was equal to nearly 9 per cent. on the capital expenditure; it was extended for a distance of 13 miles in 1896.

It having been decided to connect the two Perak railways, and to extend the Larut Railway through the Krian district and Province Wellesley to the Prai River opposite the Island of Penang, and also to connect the Perak railways with that under construction in the neighbouring southern State of Selangor, surveys were commenced in 1896; and in the following year, as soon as the surveys were sufficiently advanced, construction was commenced at several points on the new lines. The total length of the Perak and Province Wellesley Railways, as finally decided upon, is 213 miles 64 chains, of which, at the end of 1901, a length of 147 miles 31 chains was open for traffic, 29 miles was completed ready for opening, and 37 miles 33 chains was still under construction. Of the total length, 188 miles 62 chains forms part of the main trunk-line running down the Malay Peninsula, the aggregate length of the two branches, from Taiping to Port Weld and from Tapah Road Station to Teluk Anson, being 25 miles 2 chains, Figs. 2, Plate 9. The northern terminus of the railway is at Kuala Prai, in Province Wellesley, and communication is maintained between the railway terminus and George Town in Penang by a service of ferry steamers running in connection with the trains; the time occupied in crossing is 20 minutes. In Penang a steel screw-pile jetty has been constructed, running out to the 1½-fathom line, with a timber superstructure roofed with corrugated iron; a tee-head, 97 feet by 30 feet, is being constructed at the end of the jetty, also on screw-piles, placed at an angle to suit the set of the current in Penang Harbour, with suitable arrangements for the landing of passengers from the ferry steamers; provision for the warehousing of goods transported by rail is also to be made.

The ferry steamers, which have a draught of 6 feet and carry four hundred passengers, were built by the Hongkong and Whampoa Shipbuilding Company for the Federated Malay States Railways;

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they are twin-screw steamers, maintaining a speed of 11 knots, and have proved well adapted for the purpose for which they were built, being easily handled and navigated through the shipping which crowds the Port of Penang; the captains and crews are Malays. Passengers only are carried by these steamers, but they are also fitted up for the conveyance of horses and carriages. Goods carried by rail and intended for transport to George Town are shipped into lighters at Kuala Prai, which are towed across the channel between the mainland and the Island of Penang by the ferry-steamers in the intervals of the passenger train-service; goods for transport by rail are dealt with in a similar manner.

From Kuala Prai the line runs, for the first 36 miles (of which 23 miles 19 chains is in Province Wellesley), through cultivated land, with sugar, cocoanut, and tapioca plantations intermingled with padi or rice-fields of considerable extent. Numerous canals used for the transport of sugar-cane are crossed on bridges of 15 feet span, several unimportant rivers on spans of 40 feet to 80 feet, and, at the 21st mile, the Krian River is crossed on a bridge of two spans of 150 feet and two spans of 100 feet. Between the 36th mile and the 42nd mile the country is low-lying, thickly-wooded, and swampy. The impounding reservoir for the Krian irrigation-works is crossed on an embankment 12 feet in height, through which there are bridges of 40 feet and 65 feet span for the Tengah and Merah Rivers, and at the 46th mile the Kurow River is crossed on a bridge of 150 feet span; the line then runs almost due south and through the mining district of Kamunting till it reaches Taiping, at the 59th mile. On this section the line is principally in embankment; there are thirteen bridges of 40 feet span and upwards, eighty-two bridges of less than 40 feet span, and forty-two culverts. The aggregate length of the curves is 10 miles 50 chains, of which 6½ miles consists of curves of greater radius than 28 chains. The sharpest curves are of 15 chains radius, with the exception of a curve of 12·22 chains radius, in Kuala Prai station-yard. The steepest gradient is 1 in 150, but of this there is only 23 chains length, and there is 32 miles of level line. The short lengths of 1-in-150 gradient were introduced to raise the line at the Krian River crossing, in order to give greater headway for tongkongs and junks passing up and down the river. The earthwork averages 31,000 cubic yards per mile.

On the next section of line, Taiping to Kuala Kangsar, a length of 19 miles 13 chains, the character of the country changes

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completely; for one-half of the distance the line is of the type of a mountain railway with heavy works, steep gradients, reverse curves, tunnels and retaining-walls. There are 7 miles 76 chains of 1-in-80 gradient, 1 mile 45 chains of 1-in-200 gradient, and only 2 miles 61 chains of level line; there are fifty-nine curves, having a total length of 7 miles 66 chains, of which twenty-nine curves, having a length of 3 miles 5 chains, are of 10·86 chains radius. There are six bridges of 40 feet span and upwards, five bridges of less than 40 feet span, and eighty-three culverts. The four tunnels on this section have an aggregate length of 869 lineal yards, and there are 112 lineal yards of cut-and-cover work. The earthwork and rock-excavation is estimated at about 80,000 cubic yards per mile.

Leaving Kuala Kangsar the line crosses the Perak River at the 83rd mile on a bridge of seven spans of 150 feet, and then rises with a gradient of 1 in 150 for a distance of 3 miles 60 chains as it emerges from the Perak River valley and crosses the watershed into the Kinta River valley; Ipoh, the principal town of the Kinta district, on the banks of the Kinta River, is reached at the 112th mile. From Ipoh the line is continued down the Kinta River valley, crossing the Pari, Kinta and Kampar Rivers; it then rises with a gradient of 1 in 200 for a distance of about 2 miles, and descends into the valley of the Batang Padang River; Tapah Road Station, the junction of the Teluk Anson branch, is at the 145th mile. This section of the line is of much the same character throughout; the earthworks are moderately heavy, averaging about 50,000 cubic yards per mile, but the amount of bridging is considerable. The aggregate length of the curves between Kuala Kangsar and Teluk Anson, a distance of 83 miles 51 chains, is 12 miles 49 chains, the sharpest curves being of 15 chains radius, but for a total length of 13 chains only. The gradients in general are easy, there being 27 miles 21 chains of level line, 16 miles 22 chains with easier gradients than 1 in 400, and 21 miles of gradients between 1 in 150 and 1 in 200. There are twenty-one bridges of 40 feet span and upwards, seventy-five bridges of less than 40 feet span, and seventy culverts.

Between Tapah Road Station and the junction with the Selangor Railway at Tanjong Malim, a distance of 43 miles 76 chains, the line is almost entirely through heavy forest; it crosses several rivers requiring spans of 150 feet and upwards, and the earthworks are heavier than in the preceding section, averaging 58,000 cubic yards per mile. The ruling gradient is 1 in 100, and of this there are 5 miles 42 chains; of gradients steeper than 1 in 250 there are

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altogether 22 miles 17 chains, and there are 12 miles 28 chains of level line. The aggregate length of the curves is 11 miles 12 chains, all the curves being of greater radius than 20 chains except one, which is of 14·47 chains radius for a length of 20·46 chains.

Branch Lines.—The Port Weld branch-line, constructed in 1884–1885, is 8 miles 24 chains in length, and is practically a straight line, there being only two curves, having an aggregate length of 32 chains, outside station limits; the steepest gradient is 1 in 300, but a length of 4 miles 38 chains is on the level. This line is chiefly in low embankment, and for more than half its length through swampy ground; there are five small bridges not exceeding 15 feet span, and five culverts.

The Teluk Anson branch-line, 16 miles 58 chains in length, runs through heavy forest throughout its entire length; for the first 4 miles from Tapah Road the country is gently undulating, after which the line is through a perfectly flat country with one long low continuous embankment till Teluk Anson is reached. The steepest gradient is 1 in 225, and the sharpest curve is 25 chains radius; there are several long straights, the longest measuring 4½ miles; there are three bridges, the principal one being that over the Bidor River.

Earthworks (Figs. 3, Plate 9).—The width of the embankments at formation-level is 16 feet, the slopes being 1½ to 1; cuttings in general are 18 feet in width at formation-level, but in cuttings over 1,000 feet in length the width has been increased to 20 feet to facilitate drainage, and in rock-cuttings the width has been reduced to 16 feet. The usual slope of the cuttings is 1 to 1, but in some cases it has been found necessary to flatten them to 1½ to 1; rock-cuttings are excavated with ¼ to 1 slopes. It has not been found necessary to turf the embankments, although this has been done in one or two cuttings with flat slopes, to prevent erosion, but all banks have been planted with grass, which grows readily in the tropics. Most of the embankments were made up from side cuttings, all excavation from cuttings, with the exception of a length of 2 chains at each end, being in general taken to spoil; but in places where the line crosses swamps, and borrow-pits alongside the line were impracticable, earth for the embankment had sometimes to be transported for long distances by train, and afterwards carried forward by hand in baskets. Light rails and tip-wagons, holding about ⅔ cubic yard, were extensively employed, but most of the earthwork was done by baskets with Indian (Tamil) and Chinese labour. Rates of pay vary considerably and are dependent on the

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locality, higher rates being always paid for work away from towns, and in unhealthy or uninhabited districts.

Bridges.

With few exceptions the abutments and piers of the bridges are constructed entirely of brickwork in cement, the superstructures of steel lattice- or plate-girders. The more important bridges are—

Krian Bridge	At the	21st	mile	550	feet	in length.
Kurow „	„	46th	„	150	„	„
Victoria „	„	83rd	„	1,050	„	„
Pari „	„	114th	„	180	„	„
Kinta „	„	120th	„	200	„	„
Batang Padang Bridge	„	144th	„	150	„	„
Bidor Bridge	„	154th	„	150	„	„
Sungkai „	„	162nd	„	150	„	„
Bernam „	„	189th	„	200	„	„
Bidor Bridge on the Teluk Anson Branch.				550	„	„

Krian Bridge consists of two spans of 150 feet and two spans of 100 feet; it crosses a tidal river having a depth of 35 feet at high water of spring tides. The centre pier is constructed of two cast-iron cylinders built in segments, each cylinder being 8 feet in diameter, reduced to 7 feet in diameter at the top, sunk to a depth of 44 feet below the bed of the river, and filled with 6-to-1 concrete; these cylinders are connected from the top to a depth of 6 feet below low-water level by steel diaphragm-plates stiffened with angle-bars. The other two piers are built on brick wells, 12 feet in diameter and 3 feet in thickness, sunk to a depth of 64 feet to 67 feet below ground-level. The abutments are also carried on brick wells sunk to a depth of 34 feet to 53 feet below ground-level, and filled with 8-to-1 concrete. The girders of the two centre spans of this bridge were built on staging on the bank of the river, and were floated into position, each end of a girder being carried on a pair of 80-ton iron barges braced together; the end spans were erected on staging in position. The height of this bridge is 92 feet from the bottom of the centre cylinders to rail-level.

Kurow Bridge is a single-span bridge of 150 feet span; the abutments are on brick wells filled with concrete, sunk to a depth of about 20 feet below the bed of the river; the girders were erected on staging in position.

Victoria Bridge (Figs. 4, 5, and 6, Plate 9), over the Perak River, consists of seven spans of 150 feet. Each abutment is carried on circular brick wells, six in number, sunk to the rock and concreted.

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The piers are founded on double-octagon brick wells 34 feet in length by 17 feet in width (Figs. 6, Plate 9). The brick wells rest on steel curbs 4 feet in height, of the same shape, and weighing 11½ tons each. In sinking the wells, artificial islands of sand-bags and boarding secured to piles and filled in with sand were formed in the river, and on these the steel curbs were pitched and riveted together. Brickwork was then commenced, and was carried up to a height of about 15 feet, bolted throughout with heavy iron bolts connecting the curb to the brickwork. The wells were then sunk by excavating the sand in the centre. As the wells sank, brickwork was added, and this process was continued until the rock was reached at a depth varying between 14 feet and 21 feet below the bed of the river. The rock was then chiselled off to secure a level bed for the curbs, and the central portions of the wells were concreted. The wells were finished off at a level of 6 inches above ordinary water-level, and varied in depth between 18 feet 6 inches and 25 feet. The piers are 34 feet in height, and measure 32 feet by 11 feet at the bottom, reduced to 30 feet by 9 feet at the top, with semi-circular ends. The brickwork is set in 3-to-1 cement-mortar, and the pointing is in neat cement. Machine-made bricks of standard size were used, special plant being erected for making the bricks. The superstructure, of lattice-girders 14 feet 4 inches in height, with overhead bracing, and having cross-girders at intervals of 10 feet to carry the rail-bearers, was erected on staging in position, by Chinese and Indian workmen under the supervision of a European foreman. One end of each girder is carried on a fixed bearing, and the other end on a frame containing six hardened steel rollers, 3¼ inches in diameter, to admit of expansion and contraction. A 6-foot pathway is provided at one side of the bridge for foot passengers. This is carried on prolongations of the cross-girders, Figs. 5, Plate 9. The Perak River is liable to heavy floods in the rainy season, and trees of over 100 feet in length and 4 feet to 5 feet in diameter are sometimes brought down by the flood. The height of the bridge is fixed so that there is a clear headway of 8 feet at the highest known flood-level—that of 1897. This gives a height of 41 feet from the bed of the river to the underside of the main girders. The cost of the bridge was $454,320 (about £45,000).[1]

[1] The constant fluctuation in the sterling value of the dollar during the time these railways were under construction renders it impossible to give the exact equivalent in pounds sterling of dollar figures; those figures given in pounds sterling must only be considered as approximate.

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Pari Bridge consists of one span of 100 feet and two spans of 40 feet. The abutments and piers are in brickwork in cement on beds of concrete, put in in open founds. The 100-foot girders were erected on the river-bank and swung into position by derricks, the 40-foot spans being launched into position.

Kinta Bridge has two spans of 100 feet each. The abutments and pier of this bridge are on brick wells sunk to the rock at a depth of about 27 feet below the bed of the river, and afterwards filled in with concrete. The wells for the pier, 12 feet in diameter, were built on hardwood curbs pitched on an artificial island formed of sand-bags and piling, and were sunk in the same manner as those of the Victoria Bridge. The wells were corbelled over below ordinary water-level to carry the pier. In the case of the abutments the corbelling was just below ground-level. The girders were erected on staging in position.

Batang Padang Bridge is a single span of 150 feet; the foundations for the abutments are cast-iron cylinders 6 feet 6 inches in diameter, sunk to a depth of 18 feet below the bed of the river, and concreted. On the tops of the cylinders, which are pitched 1 foot 6 inches apart, a bed of concrete 4 feet in thickness was laid, and on this the brickwork was commenced; the girders were erected on staging in position.

Bidor Bridge (Figs. 7 and 8, Plate 9) consists of five spans of 100 feet and two land-spans of 25 feet; the piers are each composed of a pair of cast-iron cylinders, 6 feet 6 inches in diameter, connected by a steel diaphragm, sunk to a depth of 35 feet to 56 feet below the bed of the river and filled with concrete; the abutments are of brickwork on piled foundations. As the bridge crosses a tidal river with a bottom of soft black mud, any attempt at the erection of staging was impracticable; the girders were therefore erected on the bank of the river, and as each pier was completed a pair of girders was hauled out on to two wooden pontoons and floated into position. The pontoons were then anchored, and as the tide fell the girders dropped into their places. The time occupied in the erection of this bridge was 18 months, and the cost of the bridge was $107,591 (about £18,000). The principal difficulty experienced was in procuring materials; stone for concrete had to be brought from the island of Penang, a distance of about 130 miles by sea and 39 miles by river, and bricks for the abutments were brought from Province Wellesley, about the same distance. Only Chinese workmen were employed, under a European foreman. Of the smaller bridges, the foundations of those between 100 feet and 40 feet span are chiefly on brick wells or iron cylinders filled

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with concrete, it having been found impracticable to make use of open founds, except for some bridges not exceeding 40 feet span, on account of the sandy or peaty nature of the sub-soil, which is generally saturated with water. This, and a rainfall of over 160 inches a year in some parts of the country, necessitated extensive pumping arrangements where open founds were adopted, and the country being covered with jungle or heavy forest, the transport of boilers and pumping machinery was a matter of extreme difficulty. All girders of 100 feet to 65 feet span are of the lattice type and were erected on staging, with the exceptions already mentioned. The 40-foot, 25-foot, 20-foot and 10-foot girders are all plate-girders, and were erected either by launching over a light scaffolding or were riveted in position on a staging supported on sleeper-cribs.

Works.

Culverts.—The culverts are of three types, viz., rail-openings, arches, and slab-topped culverts; a few pipe-drains were made use of through low banks where the catchment area was small. The rail-openings vary between 6 feet and 2 feet, small built girders being used in the former; the arches vary between 6 feet and 3 feet; the slab-topped culverts are all of 3 feet opening, but in some cases two or three openings have been placed side by side in place of building a 6-foot or 9-foot arched culvert. The advantage of using slabs of stone for covering culverts is that the embankment can be tipped as soon as the slabs are in position, there is no danger of collapse in the case of unequal settlement of foundations, and the risk of bad workmanship in arches is avoided. A few cast-iron cylinder-culverts, 6 feet 6 inches in diameter, were constructed from spare cylinders sent out for bridge piers; these were bedded in concrete.

Tunnels (Figs. 9, Plate 9).—There are four tunnels on the section between Taiping and Kuala Kangsar. The ordinary section of tunnel adopted has a width of 15 feet and a height of 17 feet from rail-level, but the lined portions at the ends of tunnel No. 2, and the cut-and-cover work, have been constructed with a height of only 14 feet 9 inches from rail-level, with the object of affording greater resistance to lateral pressure where there is no great height above the crown of the arch. In all cases the tunnels are through hard granite rock, except for short lengths at the ends, which were lined with brickwork set in cement-mortar, the greatest length of lining at the end of any tunnel being 45 yards. Work was commenced by driving a heading at the top of the tunnel, a narrow-gauge tramway being laid in the heading and extended as

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the work proceeded. For tunnel No. 2 a shaft at the summit of the gradient was sunk in addition, so that work could be carried on simultaneously at four places. For the rock-work Schram "Optimus" compound drills were used, worked by air-compressors driven by a 12-HP. vertical cross-tube boiler. The greatest length of heading driven per month with one set of drills was 121 feet, and in breaking-down the greatest length completed in a month was 66 feet. Only Tamil labour was employed, under European foremen. Nobel blasting gelatine was almost exclusively used for work in the headings, and for breaking down, as it proved more satisfactory than dynamite.

Permanent-Way.—The gauge of the Perak and Province Wellesley Railways is 1 metre (3 feet 3⅜ inches); the greater part of the road is laid with flat-bottomed rails weighing 60 lbs. per lineal yard, a standard section of that weight having been adopted since 1895 in the Federated Malay States. The Larut and Kinta Valley lines, constructed between 1884 and 1895, having a total length of 67 miles, are laid with rails weighing only 46½ lbs. per lineal yard; on these lines the sleepers, which are of native hardwood, are 6 feet 6 inches in length, 9 inches in width, and 4½ inches in thickness, the space between the sleepers being 1 foot 8 inches. On all lines constructed since 1895, rails weighing 60 lbs. per lineal yard have been used, and the sleepers are 6 feet 6 inches in length, 10 inches in width, and 5 inches in thickness, the space between the sleepers being 1 foot 10 inches. Rails are secured to the sleepers with dog-spikes, clip-bolts being used at the joints on curves. The line is ballasted for the greater part of its length with broken limestone, but in the mining districts washed gravel has been largely employed, and in some parts of the line, where no stone or gravel was procurable, river sand has been used. Sand was exclusively used on the Teluk Anson branch when the line was constructed, but after rails were laid into the district of Kinta all curves were packed and boxed in with broken stone ballast. In Province Wellesley and the Krian District the ballast used was to a great extent broken stone, brought in sailing-barges from the Island of Kra, off the coast, and trained out as the rails were laid The width of the ballast is 8 feet 6 inches and there is a depth 6 inches under the sleepers, the quantity of ballast used bei 2,000 cubic yards to the mile.

Stations.—There are forty-two stations on the line at distances varying between 2 miles 33 chains, and 12 miles 25 chains apart. With four exceptions, sidings are laid at all the stations to provide for goods traffic and the crossing of trains. The crossing-sidings

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have sufficient length for a train of forty-five wagons. The platforms are 300 feet to 400 feet in length, 16 feet in width, and, in general, are raised 1 foot 3 inches above rail-level; one or two of the earlier constructed stations have platforms raised to the level of the floors of the carriages; the unimportant stations have platforms raised only 6 inches above rail-level. The goods-sheds have platforms raised to the floor-level of the trucks, and are constructed of hardwood framing on brickwork foundations. They are usually constructed on a loop on the opposite side of the main line to the passenger building, as this arrangement enables shunting to be expeditiously carried out by trains running in either direction, and places the goods-yard under the close supervision of the station-master.

Workshops, &c.—The accommodation provided is at present of a newhat temporary nature, as it is intended to establish the ermanent workshops for the whole of the Federated Malay States Railways at Kuala Lumpur, in Selangor, as soon as the Perak and Selangor Railways are connected. The present workshops are at Ipoh and Taiping, in both of which sufficient machinery is provided for the general repair of locomotives, carriages, and wagons, and for the building of new wagon-stock. Locomotive- and carriage-sheds for running purposes are provided at Ipoh, Teluk Anson, Taiping, and Kuala Prai. Tanks and engine-turntables are also provided at these stations, and there are in addition eight watering-stations, situated about 20 miles apart.

Wharves.—In Penang, a light screw-pile jetty has been erected for the landing of passengers from the railway ferry-steamers. At Kuala Prai a floating wharf has been constructed for passenger traffic, and a dock 400 feet by 100 feet to be used by barges carrying goods to or from the railway. At Port Weld a wharf has been constructed of hardwood piles, and a wooden copper-sheathed pontoon with hinged gangways, providing berths for two steamers; and at Teluk Anson berths have been provided for three steamers by the construction of pontoon-wharves. The pontoons are constructed of iron cylinders, 5 feet in diameter and 16 feet in length, supporting a wooden platform, with hinged gangways at intervals, connected with the platforms of the goods-sheds. There is 20 feet depth of water alongside the pontoons at low-water of spring-tides, and the rise and fall of the tide is 8 feet.

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Rolling Stock.

Locomotives (Fig. 10, Plate 9).—Three types of locomotives are in use on the railway, viz., tank-engines, for shunting purposes and for local trains; four-wheels-coupled tender-engines with side-tanks; and six-wheels-coupled tender-engines without side-tanks. Of the latter the cylinders are 14½ inches in diameter by 20 inches stroke, the wheels are 4 feet 3 inches in diameter, and the gross weight of the engine and tender loaded is 48 tons 14 cwts.

Carriages (Figs. 11, Plate 9).—There are two types of carriages in use, viz., four-wheel light stock, originally provided for the Larut Railway, and bogie-stock. For the latter the carriages are 45 feet in length over the end platforms, the bodies being 40 feet by 7 feet 6 inches in outside dimensions. They are entered from the end, and there is through-communication from end to end of all passenger-trains. The roofs are double, of the clerestory type, 7 feet 3 inches in height at the centre, and 5 feet 10 inches at the sides. The bodies are carried on bogies 29 feet apart, centre to centre, with wheels 2 feet in diameter on the tread; the under-frames are of channel steel with a truss-rod on each side, and they are fitted with radial draw-bars and central combined buffing and draw-bar gear with "Jones" hook-coupling. First-class carriages provide accommodation for thirty-nine passengers, composite carriages for eighteen first-class and twenty-seven second-class passengers, and third-class carriages for eighty passengers.

Wagons (Figs. 12, Plate 9).—Two types of covered goods-wagons, carrying respectively 5 tons and 7 tons, have been adopted. The bodies of the latter are 15 feet by 7 feet in outside dimensions, the wheel-base is 8 feet 6 inches, and the tare is 3 tons 18 cwts. The wheels of all the wagon-stock are 2 feet in diameter on the tread. The covered goods-wagons are roofed with corrugated iron. The following is the present equipment of the railway:—

22 tender-locomotives.	3 four-wheel vans.
11 tank-locomotives.	19 goods brake-vans.
69 bogie-carriages.	612 goods-wagons and other vehicles.
18 four-wheel carriages.	

The most recent prices paid for locomotives and rolling-stock, freight included, are:—

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	£
Six-wheels-coupled tender-locomotive	2,625
First- and second-class composite carriages	1,340
Third-class carriages	820
Third-class and van composite carriages	890
Covered goods-wagons (7 tons)	94
Low-side iron ballast-wagons (7 tons)	68
Goods brake-vans (10 tons)	161
Horse-boxes	170
Cattle-wagons	135
Carriage-trucks	113

All wagons are fitted with hand-lever brakes; carriage-stock is at present fitted with the Clark continuous chain-brake, but it has recently been decided to fit all passenger-trains with the automatic vacuum-brake.

Working.

The line is at present worked in sections, the longest being Teluk Anson to Padang Rengas, 90 miles 44 chains; the other open sections are:—Port Weld to Pondoh Tanjong, 20 miles 40 chains; and Kuala Prai to Alor Pongsu, 36 miles 27 chains, but it is expected that all the extensions now in hand will be completed and the different sections joined up by the end of 1902. The estimated cost of the whole system is $16,923,971, which is being provided from the surplus revenue of the State of Perak, it not having been found necessary to raise the loan authorized in 1897 when the works now in hand were sanctioned. In 1900 the total receipts from the sections then open amounted to $1,017,618 (£101,761), the working expenses to $514,108 (£51,410), or 50·5 per cent. of the gross receipts; the expenditure was divided thus:—

	$	£
General management	23,339	(2,333).
Traffic department	161,518	(16,151).
Locomotive department	180,573	(18,057).
Way and works department	140,088	(14,008).
Stores department	4,075	(407).
Telegraph department	4,515	(451).

In the same year the number of passengers carried was 1,476,426, the receipts from passenger-traffic were $531,844 (£53,184), from goods-traffic $407,983 (£40,798), and miscellaneous receipts amounted to $77,791 (£7,779); the goods carried amounted to 194,036 tons, and the total traffic to 349,319 train-miles. The longest section open in 1900, that from Teluk Anson to Kuala

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Kangsar, contributed $807,848 (£80,784) to the total receipts, with working expenses of 41·56 per cent.; the capital cost of this section to 31 December 1900 was $5,061,054 or $59,894 per mile, and the profit on the year's working was equal to a dividend of 9·33 per cent. On this section the expenditure in 1900 was $1·44 (2*s.* 5⅜*d.*) per train-mile, the receipts were $3·46 (6*s.* 5½*d.*) per train-mile, the total gross traffic was 23,578,065 ton-miles, or 233,567 train-miles. The expenditure per train-mile was divided thus:—

General management	7 cents	(¾*d.*).
Traffic department	38 „	(4¼*d.*).
Locomotive department	56 „	(6¾*d.*).
Way and works department	41 „	(5*d.*).
Stores department	1 cent	(⅛*d.*).
Telegraph department	1 „	(⅛*d.*).

Rates.—The passenger fares charged are, at the present rate of exchange, equal to rather under 2*d.* a mile for first-class, 1¼*d.* for second-class, and ⅝*d.* for third-class passengers. Return-tickets are issued at the rate of a fare and a half for the double journey.

Goods are divided into six classes, the rates varying between 2 cents per pikul (8·2*d.* per ton) per mile, and ¼ cent per pikul (1*d.* per ton) per mile; on the carriage of rice, tin, and tin-ore a special reduction of 10 per cent. is made for distances over 50 miles, with an additional 10 per cent. reduction for distances exceeding 150 miles. Goods-traffic inland from the ports consists principally of rice, figs, foodstuffs, and fuel; the outward traffic consisting almost entirely of tin and tin-ore.

Staff.—In the traffic branch, Chinese and Jaffna Tamil station-masters and clerks, locally trained, are employed, under the direction of European inspectors and a traffic superintendent. The porters and pointsmen are Tamils, and the loading-coolies are Chinese and Mohammedan Tamils. The locomotive branch employs, under European supervision, European and Eurasian drivers and Tamil firemen; and in the workshops, Chinese, Singhalese, and Tamil carpenters, blacksmiths, fitters, and turners, with some few Eurasians; the coolie labour is Tamil. The way and works branch employs Tamils as platelayers and masons, and Chinese as carpenters and blacksmiths. Platelayers are formed in gangs of ten to twelve coolies in charge of a tindal or head man, each gang having a section of line 3 miles in length; the work of the gangs is supervised by a European foreman-platelayer, who has as a rule, a section of line 21 miles in length. The general

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maintenance of the road is further supervised by a European inspector, who personally superintends the repairs of bridges, culverts, buildings, wharves, and signals, under the direction of a district engineer. The line, for maintenance purposes, is at present divided into two districts.

Conclusion.—The cost of construction and equipment has varied greatly. The cost of the 17 miles in the Laruk District (1884–1891) was $45,717 per mile, and of the Kinta Valley Line (1891–95) $50,905 per mile, while the average estimated cost of the extensions sanctioned in 1897 is $93,744 (about £8,600) per mile. The cost of these extensions includes the provision of ferry-steamers, barges, and jetty in Penang harbour, and a landing-stage and dock at Kuala Prai. The estimated cost of the section between Taiping and Kuala Kangsar (19 miles 13 chains) is $163,090 (about £14,900) per mile.

The dollar, which was worth 3*s.* 10*d.* in 1890 and 3*s.* 5*d.* in the year the Kinta Valley line was commenced, is now worth only 1*s.* 10*d.*; the fall in exchange has been accompanied by an increase in the cost of local labour and materials, and in the prices of materials purchased in England.

The construction and working of these lines have, since 1887, been in charge of the Author as resident engineer and manager; the consulting engineers are Messrs. Gregory, Eyles and Waring, who selected the European staff employed, and are responsible for the design of all the bridge-tops, locomotives, and rolling-stock, and to whom the Author is much indebted for advice.

The Paper is accompanied by six tracings, from which Plate 9 has been prepared.

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(*Paper No. 3328.*)

"Pile Sinking by Means of a Hydraulic Jet at Moruya and Carrington Bridges, New South Wales."

By ERNEST MACARTNEY DE BURGH, M. Inst C.E.

THE difficulty frequently experienced in sinking screw-piles has, in some instances, led to the employment of a water-jet to facilitate the work of sinking, and communications[1] on the subject have appeared in the Proceedings of the Institution. The Author desires to acknowledge his indebtedness to these communications.

In the structures described in the following Paper the Author adopted cast-iron piles on account of their durability in teredo-infested salt water. The section of the Moruya River, at the point where the South Coast Road crosses it, shows soft granitic rock underlying sand and clay at depths varying between 4 feet and 36 feet, Fig 10, Plate 10. The bridge which carried the traffic up to the year 1889 consisted of sixteen timber spans of 50 feet each, supported on hardwood piles. In the new structure eighteen spans of 45 feet each and two spans of 25 feet each were adopted, as these spans admitted of the use of corbelled ironbark beams, and it was necessary to construct nineteen piers and two abutments. The deck is 18 feet in width between the curbs.

General Type of Pier Adopted.—Each pier consists of three cast-iron piles, 12 inches external and 10 inches internal diameter, braced as shown in Figs. 2, Plate 10. Each pile was cast in lengths of 12 feet or less to suit the conditions of sinking, and the connections between the lengths of pile were made by means of outside flanges thick enough to admit of the bolts being housed into them, so that after the bolts had been screwed up with a box-spanner they could be flushed over with Portland cement to protect them from the action of the salt water.

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[1] Minutes of Proceedings Inst. C.E. Mr. Brunlees in Discussion on "Sinking Columns," vol. xxvii. p. 309, and "South Reserve Piers and Landing-Stage head," by C. G. Smith, Stud. Inst. C.E., vol. l. p. 164.

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It was considered desirable to sink the piles of Piers 4 to 14 (thirty-three piles) to a depth of 18 feet to 37 feet, and to fix those of Piers 1, 2, 3, 15, 16, 17, 18, 19, and of the abutments, (thirty piles) in the rock, in holes excavated for the purpose. It is believed that the piles of Piers 4, and 9 to 14, reached the rock and rest upon it.

Type of Shoe.—The maximum load on each pier-pile in the finished structure amounts to 24 tons, with a full live-load of 84 lbs. per square foot of deck, and on the abutment-piles to 9 tons. Whilst the cast-iron columns with flanges, when sunk to a depth of 35 feet in sand, would probably sustain such a load safely, it was considered desirable to increase the bearing-surface by the addition of a shoe, which would also act against overturning in flood by resisting the lifting of the upstream piles. An experiment was made with a shoe of the form shown in Figs. 3, Plate 10, the cast-iron teeth being added to assist sinking in clay, or when decayed timber was met, when it was proposed to rotate the pile. In this shoe the central and only orifice was $2\frac{3}{4}$ inches in diameter; subsequently this shoe was abandoned in favour of that shown in Figs. 4, Plate 10, which is of a lighter and more simple pattern, it being found that the action of the central and radial water-jets alone was sufficient to sink the pile through the sand and a certain distance into the clay, making it unnecessary to provide teeth or rotating-gear.

Experiments were made to determine the most efficient system of orifices, and it was found that a central orifice of 2 inches diameter and four orifices of $\frac{1}{2}$ inch diameter, disposed as shown in Figs. 4, Plate 10, provided the most effective arrangement in the sand and soft clay with occasional sand-bands which were met with; but, as will be seen later, difficulties were encountered when the depth of clay to be penetrated exceeded 11 feet 6 inches, and the clay itself became more compact. Although the size of these orifices may be increased, with a corresponding increase in the pumping-power, no advantage is gained in sinking in sand, while the disturbance at the bottom is unnecessarily increased. On the other hand, the piles might be sunk successfully in sand with a smaller supply of water than that used at Moruya, for, in the course of experiments conducted by the Author, a pile was sunk 10 feet in compact sand with a high-pressure Mumford boiler-feed-pump delivering only 30 gallons per minute, and sinking was only stopped by the pile encountering a very stiff bed of clay. It would appear, however, that the plant about to be described fairly fulfilled the requirements as to efficiency and portability.

Plant used for Sinking Piles.—The water-jet was supplied by

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a Worthington pump, having two steam-cylinders 10 inches in diameter and 10 inches stroke, and two water-cylinders 6 inches in diameter and 10 inches stroke, capable of delivering 250 gallons of water per minute, and working up to a pressure of 160 lbs. per square inch. Steam was supplied by a 12-HP. vertical boiler with four tubes, working at a pressure of 80 lbs. per square inch. A 6-inch armoured rubber suction-hose was used, and the delivery-end was connected to a length of 5-inch steel pipe laid in a convenient position along the edge of the pontoon which carried the plant; from this steel pipe branched four connections, one 4 inches, one 2½ inches, and two 1½ inch in diameter, while a spring-valve was provided to prevent sudden shocks to the pump. The intermediate connection between the head of the pile and this steel main was made by a 4-inch armoured rubber suction-hose, a steel U-piece being provided at the head of the pile, Figs. 6, Plate 10. The U-piece was fixed in a gland to admit of the pile being rotated if necessary. The water was pumped into the pile itself, no internal pipe being used. A Marsh air-compressor, having a steam-cylinder 10 inches in diameter and an air-cylinder 10 inches in diameter and 12 inches stroke, was fed from the same boiler as the Worthington pump and supplied air for the air-lock. The air-lock consisted of a steel cylinder 3 feet 6 inches in internal diameter, built in one 5-foot and two 10-foot segments, with an upper chamber, 4 feet 6 inches in diameter and 6 feet in height, having attachments for both the 4-inch water-delivery from the Worthington pump and the 2-inch air-delivery from the Marsh compressor, Figs. 8, Plate 10. A steam-winch, with an independent 6-HP. boiler, and a 3-ton hand-winch were used for hoisting.

Of this plant the Worthington pump and the winches alone were sufficient for the general work of sinking the piles, the air-lock and compressor being for the special purpose of removing timber which, it was anticipated, might be met with embedded in the sand, and also to reach the rock in which the piles of Piers 1 to 3 and 15 to 19, and those of the abutments, were fixed.

Temporary Structures.—As it was necessary to provide for traffic during the progress of the work, the new bridge was built in two sections, and a side-track, 17 feet in width, supported on timber piles, was constructed before each section of the old structure was removed. The hardwood piles of this side track, sixty in number, were each sunk a distance of 16 feet, on an average, by means of a jet, the water being carried down the side of the pile in a 2-inch pipe, and thence into a 1¾-inch auger-hole in the point of the pile,

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as shown in Figs. 6, Plate 10. This arrangement was adopted, as it was found that unless the jet was kept central, and following the direction of the axis of the pile, straight sinking could not be attained, the pile following the direction of the jet. The average time occupied in sinking each pile, after it was placed in position, was 4 minutes, being the actual time in motion; and as the piles were supported and lowered from a derrick, no pile-frame being necessary, little delay was occasioned by shifting gear. The pump-gauges indicated a pressure of 5 lbs. to 7 lbs. per square inch, except when clay bands were met, when the pressure would run up to 30 or 40 lbs. per square inch. The piles were of hardwood, 14 inches in diameter at one end, 9 inches in diameter at the other, and 40 feet in length, and weighed 1¼ ton each. No additional weight was needed to sink them, and directly the pump was stopped the pile set firmly in whatever position it happened to be at the time. No test was made of the sustaining power of these piles; they supported the load of 10 tons each which came upon them, in conjunction with the vibration caused by the traffic passing over a rough deck, without movement, and it would appear that the sand settled round them, in a short time, as firmly as if it had not been disturbed. It is probable that a number of these piles reached the clay, and in some cases penetrated the upper soft portion of it for some distance; at the north end of the bridge, where little or no sand was encountered, they were sunk into clay as far as the jet would take them.

Sinking Piles of Piers 4 to 14.—The position of each pile having been fixed, borings were taken with an iron pipe 2 inches in diameter, which, coupled to the pump, penetrated the sand with the greatest ease, enabling any change in the strata, or the presence of any obstruction, to be accurately located. During the sinking of eleven of the piles, drift timber was encountered embedded in the sand, and where this timber consisted only of small branches, or even heavier timber well riddled by *Cobra*, no difficulty was experienced in sinking the pile through it, for it would appear that the action of the jet caused the sand, for some distance round the pile-shoe, to become fluid, so that the timber was easily pushed aside or broken. When, however, heavy sound logs were met with, it was necessary to use the air-lock, as described later, to clear a passage for the pile. In the case of the remaining twenty-two piles, no obstacle was encountered.

The guides consisted of four hardwood timbers, faced with iron plates, and fixed as shown in Fig. 5, Plate 10, to bear upon the flanges of the pile; it was found advisable to have these guides as

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long as could be conveniently arranged (20 feet in this case), and, although an average length of 30 feet of pile was sufficient to reach the required depth and finish at water-level, an additional length of 15 feet, in five segments, was added, so that the guides might still be effective when the required depth of sinking was approached. The use of short lengths for the upper portion of the column gave a better bearing against the guides than if the flanges were less frequent, and additional weight, obtained by working with a long column, facilitated sinking when stiff strata or any obstruction was encountered. The removal of a portion of the guides enabled the air-lock cylinder to be introduced in place of the pile if necessary. The Worthington pump was capable of working up to a pressure of 160 lbs. per square inch, but directly it was set in motion the pile was found to penetrate the sand rapidly, although the pressure on the water-gauge would only range between 5 lbs. and 7 lbs. per square inch; and it was found necessary to support the weight of the pile by a steel rope from the derrick, and so control the sinking by paying out from a hand-winch. So low was the pressure needed for sinking in sand that the column of water in the pipe would, by its own pressure, escape from the shoe in jerks, thus causing a partial vacuum in the head of the pile, so that if plain rubber delivery-hose was used for the water-supply, as was done at first, it would constantly collapse near the head of the pile, filling again as the pump supplied the void. This constant "breathing" of the hose wore it out, and was the cause of the adoption of the suction-hose for delivery which has already been referred to. It will be seen, therefore, that, had a large supply of water at a fair pressure been available, from such a source, for instance, as a town water-supply, it might well have been used for sinking the piles, and the pumping-plant dispensed with; such a system would, however, necessitate the work being carried on in a continuous line from the source of supply, which is not necessary with a portable plant such as that described.

The time occupied in sinking a pile through the sand overlying the clay, an average depth of 14 feet, after it was placed in position, averaged 6 minutes, inclusive of the time occupied in shifting the gear. The actual rate of movement was about 8 feet per minute, but this was always regulated by the check-rope, so as to prevent any sudden run of the pile taking it out of position. No appreciable variation was found in the speed or ease of sinking in sand at various depths, until the clay was reached, nor was any great difference noticed at the Carrington Bridge, where similar piles were sunk in sand by the same

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process to a depth of 20 feet. It is of importance to notice, however, that the fact of the sand being covered by water makes sinking much easier than if the surface is dry; so much is this the case that when the sand was exposed at low-tide it was found desirable to excavate a channel to the point where a pile was to be sunk, and so flood the surface round the pile. When the clay was met with, the pile stopped suddenly and the pressure of the water in the delivery-hose rose to 40 lbs. or 50 lbs. per square inch and higher, the limit not being recorded, as the gauge did not register above 50 lbs. per square inch. As it was necessary to continue sinking, the weight on the pile was increased (by pulling down with a winch) to about 10 tons, the pump being kept steadily at work; after a lapse of 5 minutes to 10 minutes the pile would sink 6 inches to 9 inches. This operation was repeated until the penetration became very slow, which occurred after an average depth of 11 feet 6 inches of clay had been passed through. There is no doubt that this limit to sinking in the clay may be attributed to three causes:—(1) The compact nature of the clay met with at that depth; (2) the resistance caused by the strata closing in under the flange-joints of the pile; (3) the failure of the shoe to clear well. In the case of the piles (twelve in number) of Piers 5 to 8 inclusive, the average depth of 9 feet 3 inches which they reached in the clay, under a 10-ton load and the action of the pump, was considered sufficient, on account of their position in the current of the river. These piles were loaded as described later to test their bearing-power only, but in the case of the piles (eighteen in number) of Piers 9 to 14 inclusive it was considered desirable to press the sinking as far as possible, and with this object in view the pumping was continued until an average depth of 13 feet 8 inches in clay was reached, under the 10-ton load, and movement practically ceased. The pump was, however, kept working for 2 hours to 3 hours longer, and additional loading up to 32 tons per pile was applied, which produced an average additional penetration of 4 feet 4 inches, making a total depth in the clay of 18 feet, on an average, for each of the eighteen piles. The clay, which was several times exposed and examined during the operations with the air-lock, was of a compact nature, with some sand-veins near the top, but stiff and tough below. The Author is of opinion that for sinking in clay the shoe used at Moruya, which was designed for sinking in sand, could be modified with advantage; for it would seem that the action of the jet softened and wore away the clay, but that the hole made had a less diameter than the shoe, upon the

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edge of which the pile remained supported until the added weight broke down the resistance. The substitution of internal screwed joints for the external flange-joints used to connect the piles would be found of advantage in deep sinking.

Use of the Air-lock.—As already stated, it was decided to secure the piles of both abutments and of Piers 1, 2, 3, 15, 16, 17, 18 and 19, in the rock, an operation which, in the case of the piers, would, on account of the overlying sand, involve considerable expense in the construction of cofferdams. It was thought necessary to provide the steel cylinder and air-lock, already described, for the purpose of removing drift which might be encountered when sinking the piles of Piers 4 to 14, and it was intended to reach the rock in which the piles had to be fixed by sinking the cylinder through the sand by the pneumatic process in the usual way. Before carrying out this portion of the work it was decided to attempt to sink the cylinder in the same manner as the piles of Piers 4 to 14, by means of a water-jet; and with this object a cast-iron door, having a central and radial orifices like the pile-shoes and designed to open inwards, was provided to close the bottom of the cylinder. On starting operations, the Resident Engineer (Mr. Beynon Reed) discarded this door or shoe, with the satisfactory result that the cylinder, with open bottom and closed top, sank rapidly through the sand when the pump was started, reaching the rock or clay without difficulty. After this first trial the six piles of Piers 2 and 3 were placed as follows:—

Sufficient length of steel cylinder to reach from rock-level to 6 feet or more above high-water level was built, with the air-lock on top, on the spot where the pile was to be fixed, the door at the bottom of the air-lock was left open, and the top door was shut, while the 4-inch delivery-pipe from the pump was attached to the connection provided for it in the top of the air-lock. The pump being started, the water rose in the cylinder until it had attained sufficient head to overcome the resistance of the sand, when it escaped from the bottom with a rush, the cylinder at the same time sinking about 2 feet. It was a very rare occurrence for the water to reach the door at the top of the cylinder, and when it did so the pressure never exceeded 10 lbs. per square inch. Pumping was continued until the rock was reached, when the supply-pipe was uncoupled and its connection closed; the air-pipe from the Marsh compressor was then attached, two men entered the lock, and the water was expelled by the air-pressure in the usual way.

In the case of Piers 2 and 3, where no clay was met with,

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examination of the bottom of the cylinder showed the rock to be quite clear of sand, and it was only necessary to excavate a hole 3 feet to 5 feet deep, in the rock, to receive the cast-iron pile. Owing to the small diameter of the cylinder used (3 feet 6 inches) this hole was excavated near one side of the cylinder, so that room remained for a man to stand at one side of a pile placed in the hole. The material excavated from the rock was removed through the air-lock and the cylinder was filled with water to the level of the river, the water being put in from the top to prevent sand entering with it; both air-lock doors were then opened and the necessary length of pile to reach from the bottom of the hole in the rock to water-level was lowered into place. In this case no shoes were fixed to the piles, the flanges of which were the same as the others used in the bridge, and the air-lock doors were circular and of sufficient diameter to admit of the pile-flanges passing through them. It was necessary to place in position only such length of pile as was sufficient to clear water-level, but not so long as to reach within a few feet of the bottom door of the air-lock; for if the top of the pile reached the air-lock door it would be impossible for men to enter to complete the work. The pile being roughly in position, the water was again expelled, and two men, entering the cylinder, plumbed the pile and fixed it in the rock with fine concrete. The water was then re-admitted, and after the lapse of sufficient time to allow the concrete to set, the pump was again applied and the cylinder was lifted with ease from its position, the sand running back into its place, completing the operation. It is difficult to convey in a detailed working description of the process, an idea of its speed and efficiency. The water-pressure required to sink the cylinder rarely exceeded 5 lbs. per square inch, and the time which elapsed from the starting of the pump until the men were standing on the rock below 9 feet of sand and 5 feet of water, was only about 30 minutes to 45 minutes. The small size of the cylinder used necessitated that a small slight man should do the work below, but there is no doubt that a cylinder 4 feet in diameter would have been sunk easily with the same pump. On the economy of the process as compared with building a cofferdam it is unnecessary to comment. At Piers 15, 16 and 17, where clay was encountered, the material was excavated under air-pressure and was sent up through the air-lock in the usual way. In the case of two of the piles of Pier 5, it was ascertained by sounding that heavy timber was embedded in the sand in the position to be occupied by the pile, and the cylinder was sunk in the manner already described until

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the timber was reached, when, the air-lock being applied, a man descended and cut a passage for the pile, which was then sunk by means of the water-jet.

Testing Sustaining Power of Piles.—It has been stated that the full load (dead and live) on each pier-pile was estimated at 24 tons. This load is based on an assumption of a live-load of 84 lbs. per square foot of deck-area, which is generally adopted as a standard by the Public Works Department of the State of New South Wales, but is rarely met with in country districts. In the case of the piles of Piers 5 to 8 inclusive (twelve piles in all), the sinking had stopped in clay, and, as the action of the water-jet was to soften and carry away the material below the pile-shoe, it was thought desirable to test the sustaining power in each case; a load of 28 tons per pile was accordingly applied, and was left in position for a period of between 24 hours and 48 hours, or longer in cases where the yield or set reached a maximum. The downwards pull applied when sinking these piles was 10 tons, and it was found that the set under 28 tons was, on an average, 4 inches. The minimum set was $2\frac{3}{4}$ inches; in this case the pumping had been continued for 12 minutes after the pile failed to move under the 10-ton load, $5\frac{1}{2}$ weeks had elapsed between the date of sinking the pile and that of applying the test-load, and the sinking was through 12 feet of sand and 4 feet 3 inches of clay. The maximum set was $10\frac{1}{2}$ inches; in this case the pumping had been continued for $2\frac{1}{2}$ hours after the pile failed to move under the 10-ton load, only 12 hours had elapsed between the time of sinking and the application of the test-load, and the sinking included 13 feet in sand and 11 feet in clay. In general, it was found that the set under the test-load increased with the proportion of clay sunk through, and with the time pumping was continued after the 10-ton load failed to move the pile; while the longer the pile was left before being tested, the less it moved.

On the completion of sinking and testing, the whole of the piles were filled with fine concrete, the object being not only to stiffen the pile but also to prevent the circulation of water, and the possible deterioration of the pile, in the event of any water finding access through the joints; the bracing was then fixed, and the superstructure completed. In the case of some of the piers, however, owing to the bracing not being ready, the superstructure was completed before the piers were braced, but the incomplete work withstood a serious flood without damage.

The Moruya Bridge was opened in 1900, and has since carried a fairly heavy traffic, and been subjected to a flood which rafted

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timber heavily against it, but up to the present time (November, 1901) no signs of movement or subsidence have been detected.

Carrington Bridge.—This bridge, like the Moruya Bridge, was erected to replace an old structure. It carries the road-traffic from Newcastle to the Dyke, on which is situated the hydraulic plant for loading vessels with coal. The new bridge has nine spans of 30 feet and one span of 35 feet, all of ironbark beams, with a 24-foot roadway, and one footpath 6 feet in width. The piers consist of cast-iron piles similar to those at Moruya, but there are five piles in each pier, the two outer piles being 1 foot in diameter and the three inner piles 9 inches in diameter, all having shoes of the same size and shape as those shown in Figs. 4, Plate 10. Reference is made to this bridge on account of the sinking being wholly in sand, and also on account of the different method adopted of testing the piles. There are forty-five iron piles in the bridge, those in the abutments, ten in number, being of timber, and, assuming a live-load of 84 lbs. per square foot of deck, the estimated load on each pile is 15 tons. All the iron piles were sunk by the hydraulic process exactly as at Moruya, to a very uniform depth of about 20 feet, in fine sand containing some layers of shells. The work was done by contract, and the plant used was not so complete or convenient as that described as used at Moruya, but the water delivery was about the same, and the sinking was very quick and easy; many of these piles were sunk in 4 minutes from the time of starting, little timber being encountered.

At the time the contract was let for this work, the Moruya Bridge was not sufficiently far advanced to enable a definite test of the sustaining power of the piles to be specified, nor had the Author any other data on the subject to act as a guide. It was anticipated, however, that very little settlement would occur in these piles, as the sand, being very fine, would probably run in under the shoe and flanges, quickly assuming its original position, and would prove very unyielding; on the other hand, the contractor frequently hung the piles up and adjusted them to an exact level to save fitting-pieces, continuing the pumping the while to keep the sand fluid—a system not to be encouraged, as it would appear to increase the risk of a void under the shoe. It was decided to weight some of the piles to 18 tons, and the first two piles so tested gave no sign of yielding although the load was left on for several days; in the case of two other piles, however, where the depth had been adjusted by the means already referred to, yields of 1½ inch and 2 inches respectively were recorded under

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the load. As this yield was very small and evidently due to the disturbance of the sand only, and the cost of loading was considerable, experiments were made to ascertain whether the desired result could not be obtained equally well by giving each pile a few light blows with a pile-engine which was available. A timber head was placed on the piles to protect them from injury, and twenty blows were given with a 25-cwt. monkey, the drop being gradually increased from 3 feet to 5 feet. The whole of the piles were treated in this manner with very uniform results, the general set being about 2½ inches, and the maximum set in any case 3½ inches, and it was found, on placing the 18-ton test-load on several of the piles after they had been tested with the monkey, that no further subsidence could be obtained. On the other hand, when the monkey-test was applied to the piles which had previously been loaded, a further set was obtained to an extent sufficient to satisfy the Author that for the purpose of settling the piles the monkey-test was not only the cheaper but also the more reliable of the two. A sum of 20*s.* per pile was paid for making this monkey-test, but the actual cost was under 15*s.* per pile.

The Carrington Bridge was completed and opened in August, 1900, and has since carried a heavy and continuous traffic. In no case has the slightest subsidence of the piles occurred.

Since the conditions as to situation, rates for carriage, and labour vary so much, the Author does not propose to give a detailed account of the cost of the pile-sinking, but hopes that the particulars given as to plant, etc., will enable a satisfactory estimate to be made to suit individual cases. It may be stated, however, that the total cost of Moruya Bridge was £9,403 6*s.* 6*d.*, or £10·78 per foot run of structure (about 12*s.* per square foot of deck). The metal work in the piers weighed 138 tons, and cost £1,975 delivered, or £14·3 per ton. The timber in the superstructure, 3,875 lineal feet round, and 10,150 cubic feet hewn, sawn and planed, cost £1,690, leaving a sum of £5,738 for plant, sinking the piles, working and erecting the timber in the superstructure, providing, erecting, and taking down the temporary bridge, dismantling the old bridge, completing the approaches, and supervision.

The cost of the Carrington Bridge was £4,725, or £15·3 per foot run of structure (about 10*s.* per square foot of deck), but any comparison with the Moruya Bridge is difficult, for while the Carrington Bridge is wider, it is much more conveniently situated for supply of material and labour.

These works were designed and carried out by the Author

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under the direction of Mr. R. R. P. Hickson, M. Inst. C.E., then Under Secretary for Public Works and Commissioner for Roads, New South Wales, and the Author is indebted to the present Under Secretary for Public Works, Mr. J. Davis, M. Inst. C.E., for permission to communicate the results.

The Paper is accompanied by a sheet of tracings, from which Plate 10 has been prepared.

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(Paper No. 3330.)

"On Some Methods of Steel Bridge Erection."

By WILLIAM SHARPE, B.Sc., Assoc. M. Inst. C.E.

THE methods of steel bridge erection described in the following Paper are those which were employed in the reconstruction work on the Natal Government Railway, consequent on the Boer invasion.

The condition of the destroyed bridges, as left by the Boers, usually decided the method of re-erection to be adopted, other governing influences being climatic conditions and the delivery of the new spans. The work of destruction was, in general, very complete, and deviations by means of temporary trestle-bridges were constructed at the larger spans; where it was considered necessary, on account of the advancing wet season, "semi-permanent bridges," also of timber trestle-work, were erected on the permanent centre-line of the railway, special arrangements being made in order that these might serve as staging for the erection of the permanent spans, as well as carry the running road. These "semi-permanent bridges" were made subsequently to the deviations, since it was most necessary that the line should be opened as quickly as possible after the troops had cleared the country of the enemy, and the latter were more simple structures than the former. The bridges are for a single track, and, so far as weight of girder is concerned, some may be classed as "medium" and some as "maximum."

To illustrate three modes of erection for large spans, the methods adopted at Colenso, Waschbank, and Standerton may be taken; the 50-metre span at the last-mentioned place was erected by the Natal Government Railways.

Bridge at Colenso.—At Colenso the rail-level is 40 feet above ordinary water-level, and this necessitated high staging, which consisted of trestles supporting longitudinals on which flooring was laid, transversely, to carry the load and to form a working platform; when possible, single trestles were used, but, owing to

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the height of the staging and the limited supply of long timbers, the trestle-work for some of the five spans over the Tugela was constructed in two tiers. The railway-line was carried by a temporary timber trestle-bridge, placed alongside the destroyed bridge and at a much lower level, so that the new spans were erected clear of the traffic.

The clear span is 100 feet, and the distance from centre to centre of bearings is 105 feet; six trestles per span were used, the end trestles being hard up against the piers and abutments. As the work was carried out during the dry season, the flow of the river was confined to the three centre spans, and concrete foundations had to be placed in the river to carry the various trestles; these foundations were not continuous throughout the length of the sills, a space being left in the middle, clear of the plumb posts. A rough timber frame, the size of the required concrete, bearing under the plumb posts and batter posts, was sunk in the river and packed with concrete in bags, the upper surface being carried above water-level and finished off with a layer of ordinary concrete. Under the trestles of the end spans a layer of sleepers provided sufficient bearing; they were, of course, laid transversely to the sills and on a levelled bed. The trestles were cut and framed, at a convenient spot on the bank, to heights calculated from the level of the foundations and from rail-level; the sills, caps, and posts consisted of pitch-pine timbers, 12 inches by 12 inches in cross-section, the posts being checked into the caps and sills, which were drawn hard on to the posts before any holes for fastenings were made, and these consisted as far as possible of flat fish-plates secured by wood-screws; diagonal bracings of deals, 9 inches by 3 inches in cross-section, were run from the extreme ends of the sill to the opposite end of the cap, and were secured at their intersection with the cap, sill, and posts by 1-inch bolts, a bolt also being passed through their own intersection, where a block, 12 inches by 12 inches, was inserted as a distance-piece. Where two tiers of trestles were used, the cap of the lower trestle was made the same length as the sill of the upper trestle, and 1-inch bolts were passed vertically through their ends, while these caps and sills were connected with the intermediate longitudinals, which rested upon the caps of the lower tier, by means of iron dowel-pins 1 inch in diameter. The caps were further secured to the plumb posts by dowel-pins, or by long 1-inch bolts driven from the top side through the cap and into the post, a hole having been previously bored. The trestle for the semi-permanent bridge at Vaal River is shown in *Figs. 1*, while the

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form of trestle required for purposes of erection only is illustrated in *Figs. 2.*

Figs. 1.

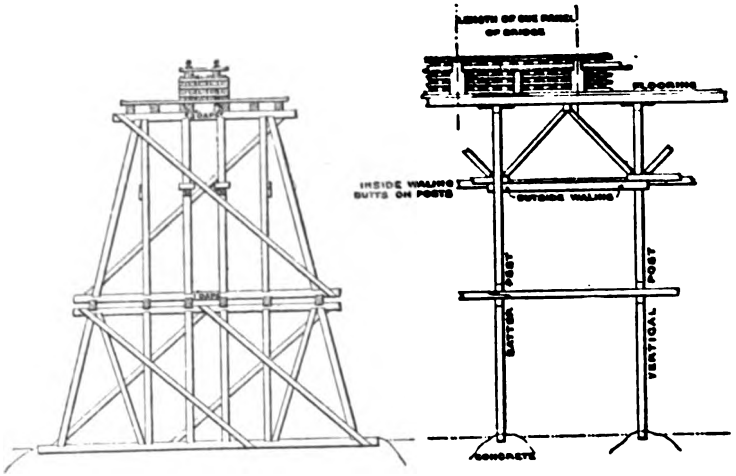

DIAGRAM OF TRESTLE FOR SEMI-PERMANENT BRIDGE.

All the trestles were carefully fitted on the bank, their members being then taken apart and re-assembled with their sills resting

Figs. 2.

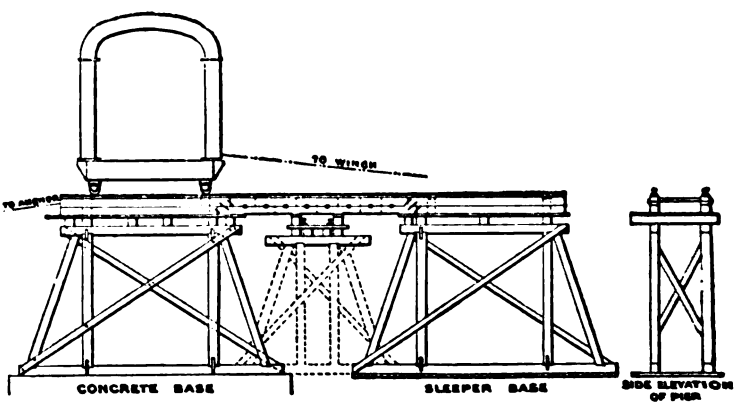

DIAGRAM OF TRESTLE USED FOR ERECTION ONLY.

over their respective foundations, with the exception of one, which had to be placed out of position to allow the remaining five to be

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raised in place. Thus Nos. 1 and 2 might be laid with their caps towards the right (*Figs. 3*) and Nos. 4, 5, and 6 with their caps towards the left; No. 3 would have its sill close to No. 2 foundation, and when the others had been hauled up to the vertical No. 3 was hauled up and pinched from foundation No. 2 to No. 3 simultaneously; this arrangement was practicable owing to the distance between the trestles, and owing to the height, which was never greater than twice the space between the trestles. In *Figs. 3* temporary braces, 9 inches by 3 inches, are shown; these were necessary during the erection of the trestles and until the 12 inches by 12 inches stringers were fixed in place. As floods were not expected during the work, the only timber connections between the trestles were the longitudinals or stringers on the top of the caps;

Figs. 3.

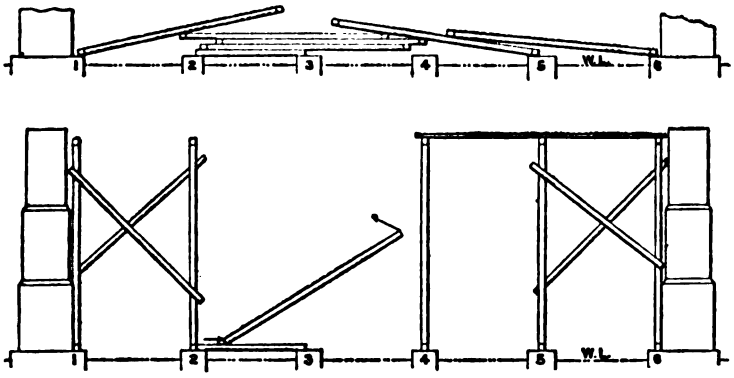

DIAGRAM SHOWING METHOD OF ERECTING TRESTLES.

of these there were four, two carrying the gantry rails, and two carrying the weight of the bridge. The former were butted over the caps, while the latter were lapped, and all were secured to the caps as already described; deals, 9 inches by 3 inches, were laid across the stringers, and formed a safe working-platform. Diagonal bracings from trestle to trestle were dispensed with, as the stringers were at such a level that they butted against the piers and abutments, care being taken that their ends fitted hard against the stone. In erecting bridges consisting of a large number of parts, economy begins with the loading of the members into trucks to be forwarded to the site, but the erector usually has his first opportunity of handling the material when it arrives at the bridge. At Colenso the original line running to the bridge was used as a siding off the deviation, and the five spans were

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off-loaded and arranged alongside the line according to their sequence; altogether, the arrangement was a most convenient one; a 5-ton bogie-crane travelled along the siding, picked up any desired piece and placed it upon a trolley, which conveyed its load to the bridge, where a travelling gantry-crane picked up the piece and placed it in position; and here it may be remarked that, in off-loading from the trucks, each piece should be so deposited on the ground that its bridge-marks may be readily seen, and that a sling can be placed around it for lifting, and also that each piece should be so placed upon the trolley conveying it to the gantry that as little work as possible should be done by that machine and on the bridge.

The booms are first laid out upon their respective bearings, with a camber always in excess of that required, as the weight of the upper booms and web-systems will compress the blocking under the bottom booms. It is advisable to erect the bottom wind-braces as the decking proceeds, since this tends to bring the panel-points to their proper positions. The end members, whether vertical or inclined, and also the posts at panel-points, are next erected, then the diagonals, and finally the top boom with its bracings; but, if the depth of the bridge is great compared with the span, it may be necessary to erect the top boom and its bracings with the verticals, in order to ensure stability, one governing principle being to make the main girders self-supporting as soon as possible in case of accident to the staging. If possible, in bridge-design, diagonal members should be so arranged that they can be put in place from the "outside," *i.e.*, that their ends do not require to be housed inside the top and bottom booms. It is of the utmost importance that the bolting together of the superstructure should be thoroughly and methodically performed, as the efficiency of the riveting depends on this to a great extent. Machine-riveting by a yoke-riveter certainly closes the plates to some extent, but hand-riveting and percussion machine-riveting require the plates to be bolted up close to one another, otherwise the first rivets inserted may be loosened by those which follow in adjacent portions of the plate, while the riveting suffers in quality, and is more severe upon those performing the work. For the erection of Colenso Bridge a gantry was used, travelling on rails laid beyond the main booms, so that there was a clear road through the bridge for the conveyance of material, and at Standerton this same gantry was used, and gave a clear road for the passage of the railway traffic; the gantry was served by two winches running on rails fixed to the cross-beams, and power was transmitted by means of shafting,

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from an axle mounted on these beams, to the supporting wheels at the rails, so that all movements were under control from the top of the gantry.

Bridge at Waschbank.—The destruction of the original bridge at Waschbank was so complete that the wreckage of the two 100-foot spans lay mixed up with the masonry *débris* of the pier and abutments in the bed of the river. The abutments and pier had all been blown up at foundation-level, and, on account of the approaching rainy season and the temporary nature of the trestle-bridge carrying the railway traffic, it was necessary to carry on the erection of the superstructure and of the masonry simultaneously. It was decided, therefore, to erect the steelwork on a stage in the vicinity, and to launch it into position when completed, and when the masonry was in a condition to bear the weight of the spans.

The "temporary crossing" was on the upstream side of the permanent railway centre-line, and 20 feet distant from it, centre to centre, so that the falsework for the new superstructures had to be placed 20 feet farther upstream, since the downstream side of the permanent site had to be left clear for the operations of the masons; thus the superstructure was built at a distance of 40 feet from its final position. The spans are similar to those at Colenso, and the staging was somewhat similar, except that at the ends of the spans it was more substantial. The first and second cross-girders are 6 feet apart, and the two end trestles were accordingly placed 6 feet apart, and exactly under the positions to be occupied by the cross-girders. They were well braced so as to form "piers" on which the launching-ways rested, being supported in a similar manner on "piers" erected at the finished abutments and pier. The general arrangements for launching are illustrated in *Figs. 2*; the span is shown on the erecting staging, and the temporary crossing is indicated by dotted lines. Cast-iron grooved wheels were secured in their bearings to the lower flanges of the cross-girders, which are underhung. These wheels were obtained from the railway stores, and obviated the necessity of constructing special bogies or other appliances. The wheels ran on 78-lb. rails, which were spiked to the upper member of a compound pitch-pine beam constructed of two timbers, 12 inches by 12 inches in cross-section, with wedges of karri wood, 3 inches by 3 inches, inserted at mid-depth and secured by 1-inch bolts from the upper to the lower face of the beam, *Figs. 2*. The manner in which the running-road was left clear for traffic until the actual time of launching is also indicated in *Figs. 2*. As a further safeguard, the launching-ways were blocked up from the stringers on the temporary crossing. They

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had a fall of 1 inch in the 40 feet, and were secured at the high end by means of wire ropes fixed to anchors in the ground. Ropes were also led to these anchors, with a warping arrangement, to be used in case of uncontrolled motion during launching, but with the arrangements described the need of such a brake is doubtful. Launching was effected by the pull from two 30-cwt. winches through a system of pulley-blocks, and the winches were effectively secured against slipping by bearing against 2-inch rods let into the rock of the river-bed, or, where rock was not available, heavy posts were fixed in the ground, and against these the winch platform bore, while the platform, extending rearwards, was weighted to prevent tilting. The launching-rails were marked every 6 inches, and observers kept tally for the guidance of those at the winches. Additional marks indicated when the span was in its correct position over the pier or abutment. The launching was carried out without a hitch, and between the passage of trains, one span being 23 minutes under way and the other 18 minutes. The height of the falsework and launching-ways was so arranged that, having been launched, the spans were jacked up to permit the removal of the ways, and, being then lowered, they rested secure upon their bearings.

Waschbank Bridge was almost entirely machine-riveted, power being supplied by compressed air, at a pressure of 80 lbs. per square inch, to two yoke machines of the Fielding and Platt type. On bridges built subsequently, the pneumatic hammer has been used, and under certain circumstances it fills the rivet-holes more effectively than the pressure-machine does, but the latter has the advantage of gripping the plate while riveting.

Bridge at Standerton.—The deviation and trestle-bridge over the Vaal River, made when the British troops occupied Standerton, were of a very temporary nature, on account of the winter state of the river and the urgent necessity of opening up the line of communication by rail, and neither the temporary earthworks nor the trestle-bridge were calculated to withstand the summer floods. Moreover, the temporary line being, at the river, about 40 feet below normal rail-level, difficulty was experienced in working the traffic upon it owing to the heavy gradients, and it was therefore decided to carry the railway by a trestle-bridge, on the main line centre, and so constructed that the new 50-metre span could be built without interruption of traffic. The trestle-work was in two tiers and was 47 feet in height from foundation-sill to cap, at the top stringers. These stringers or longitudinals were eight in number; two stringers, 16 inches by 12 inches, carried the gantry rails, two,

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16 inches by 8 inches, carried the new span during construction, and four, 16 inches by 8 inches, carried the sleeper stacks bearing the permanent-way; these last-mentioned stringers were further strengthened by raking struts, 9 inches by 9 inches, springing from the vertical posts of the trestles, which were 20 feet apart; 9 inches by 3 inches flooring rested upon the top of the stringers, being laid transversely, and the sleeper stacks extended from this flooring to longitudinals, 12 inches by 12 inches, on which the usual cross-sleepers and permanent-way were secured, the height and length of each stack being governed by the fact that the cross-girders and rail-bearers required to be put in place during the intervals between the passage of trains, one bay-length of span containing one sleeper stack, which was removed completely before shipping the cross-girders into place. In performing this operation the gantry helped materially, as its two winches raised the permanent-way slightly and so made the removal of sleepers comparatively easy, without necessitating the disconnecting of the rails, and two rail-bearers were handled simultaneously, which further reduced the time of the operation. The general arrangement of the trestles and stringers, and the disposition of the sleeper stacks, are shown in *Figs. 1.*

Vaal River Bridge has pin-connected diagonal members, and the placing of the pins and securing of their nuts at the level of the upper boom were no easy operations, especially as no arrangement for piloting the pins occurred in their design, the diameter of the screwed portion being little less than that of the body of the bolt, viz., $3\frac{1}{8}$ inches; the depth of the nuts was greater than the diameter of the screw, so that their weight was considerable, and the work of entering them upon their screws proved very troublesome. Considering the work which the screwed portion of the pin and its nut have to do, it would appear that considerable diminution of the diameter of the screw might be allowed, and at least a corresponding reduction in the depth of the nut, which should be recessed to allow of a fillet extending from the body of the pin to the screwed portion; such a reduction of the diameter of the screw also allows of a very effective piloting arrangement, as a tapered pin with a screwed socket can be made to fit the permanent pin. The mode of erection of individual members was somewhat similar to that already described for Colenso Bridge, and, as the span was designed to have no camber, allowance had to be made for settlement and also to allow the mid-portions of the upper booms to be placed in position, this portion being the last part of the boom to be erected; in this 50-metre span, about

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3 inches of camber were required to allow of the booms being completed. The question of camber is interesting, and for further comparison the new-type 100-foot span girders for the Natal Government Railways may be included. At Colenso each span weighs 108 tons and has a camber of $2\frac{3}{8}$ inches; the 50-metre span at Vaal River weighs 136 tons and has no camber; the new-type girder weighs 77·5 tons and has $1\frac{1}{4}$ inch camber. The last-mentioned gives a very pleasing appearance, and does not necessitate such an amount of cutting of the permanent-way sleepers as the $2\frac{3}{8}$-inch camber demands; the latter is excessive, since the deflection is never likely to be greater than $\frac{3}{4}$ inch; indeed, with a 45-ton locomotive—this weight being on a short base—followed by a train of wagons each of 32 tons gross weight, the deflection was $\frac{3}{8}$ inch. The span with $1\frac{1}{4}$ camber, under three locomotives of 45 tons each, gave a deflection of only $\frac{5}{16}$ inch. Vaal River 50-metre span was designed without camber, and it is scarcely possible to have a bridge thus dead level, nor is it as pleasant to the eye as when a slight camber is given. This span, having pin-connections, was bound to take the form as drawn upon the loft floor, and probably to sag a little, and in reality it has an initial deflection of $\frac{3}{8}$ inch, which increases to $1\frac{1}{4}$ inch when subjected to the heaviest load at present running on the Imperial Military Railways. The Author has allowed, in spans of 105 feet centres, $\frac{1}{4}$ inch camber upon the rails, and the results of tests show that for the usual traffic the rails are practically level during the passage of a train.

The Author is indebted to Mr. J. W. Shores, C.M.G., M. Inst. C.E., Engineer-in-Chief of the Natal Government Railways, for permission to describe the methods adopted in the recent reconstruction work.

The Paper is accompanied by five tracings and two drawings, from a selection of which the Figures in the text have been prepared.

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(*Paper No. 3352.*)

"The Teesta Bridge."

By WILLIAM ROBERT SHAW, M.E., M. Inst. C.E.

THE River Teesta is a tributary of the Brahmaputra. Rising in Sikkim, on the northern slopes of the Himalayas, it flows to the east of Darjeeling, and after leaving the hills, over 100 miles from its source, it follows a south-easterly course for a distance of 150 miles, in the alluvial plains of Bengal, before it joins the Brahmaputra 250 miles from the sea.

To arrive at the Teesta bridge necessitates a journey of 120 miles northwards from Calcutta by broad-gauge railway, to the banks of the Ganges, which is here 2 miles in width, and, being still unbridged, has to be crossed by steamer. Then follows a journey of 160 miles by metre-gauge railway. Before the bridge was built, the quickest route to Assam included, in addition, crossing the Teesta by ferry and continuing the journey by a line of 2 feet 6 inches gauge. There were thus three breaks of gauge between Calcutta and the east bank of the Teesta. The metre-gauge line to the west bank of the river, and the 2-foot 6-inch-gauge line from the east bank onwards were constructed nearly 20 years ago. The expense and difficulty of maintaining the ferry-service in a river flowing through a purely alluvial country, and so liable to change its bed that it is called by the natives the "mad" river, were very great. In the rainy season, when the river is ¾ mile in width, large launches had to be used, capable of carrying a train-load of passengers. In the dry season there is not sufficient water to float them, and all sorts of arrangements had to be improvised at short notice. The best crossing might be, say, 2 miles up the river one season, and 2 miles down-stream the next, so that several miles of sidings had to be taken up and relaid every season. The delay to traffic was great; 50 minutes was the time allowed between the two stations on either side of the river, 2 miles apart, and frequently more than twice this time

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was required. The cost of transhipment, which was naturally heavy, was recovered by an extra rate on all traffic.

The question of bridging the river had been considered more than once, and had been set aside on account of more urgent works demanding attention. It was eventually recognized that, with a steadily expanding traffic, the existing state of affairs could not last much longer, and orders were given for the work to be commenced on the previously prepared plans. When the large alluvial rivers of the Punjab had to be bridged, 30 years ago, no attempt was made to train the river into a narrower channel, and thus shorten the bridge. After carefully studying the effect of these bridges, Mr. J. R. Bell, M. Inst. C.E., came to the conclusion that it would be cheaper and better to contract the water-way by means of training-works, which would force the river to deepen its bed, and to remain in a definite channel. Acting upon Mr. Bell's observations, several of the Punjab bridges have been considerably shortened since they were originally built, with most satisfactory results, *e.g.*, the Jhelum, Ravi, and Chenab bridges. In the case of the Chenab, the original bridge consisted of sixty-four spans, of about 130 feet clear, and the river was gradually trained to pass through twenty-six spans.

The Teesta River falls rather less than 1 foot per mile, and its cold-weather flow is 8,000 cubic feet per second, with a mean velocity of 2 feet per second, and a width of 600 feet to 800 feet. During the rains the river attains a width of $\frac{3}{4}$ mile and discharges over 200,000 cubic feet per second. For a distance of 50 miles on each side of the bridge site the river flows through an essentially alluvial formation; hence, with the Punjab bridges as a guide, it was decided to train the river, and to make the bridge shorter than the flood-channel. The length finally selected (thirteen spans of 150 feet clear), depended upon conditions of scour when the river is in full flood. Orders were given to commence work in the season 1898–1899, and an assistant-engineer was appointed to the work, who built staff quarters, laid sidings down to the bridge site, and completed the stone-pitching of the right training-bund. The right bank of the river is well defined and perpendicular to the centre-line of the bridge, and the soil contains a fair proportion of clay. This was chosen as the site of the right training-bund, or the south end of the bridge.

When the Author reached the works in December, 1898, nothing had been done at the bridge beyond the collection of the curbs and some bricks with which to make a start. Arrangements were at once made to push the work. A suitable piece of ground was

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found for brickmaking, 12 miles from the works and close to the railway; no building-stone was available anywhere within a radius of 100 miles, and bricks therefore had to be used. A contractor was engaged to burn the bricks and build the masonry. Masonry pillars were built on the centre-line, clear of all works. The spans were carefully measured, and cross lines 50 feet in length were laid out through the centre of each pier, and were continually in use later, when the works were in full progress. A branch of the river, 380 feet in width, close to the right end of the bridge, was spanned by means of 30-foot steel beams resting on piles, and was strong enough to carry the construction-trains. Two of these spans were joined together and were pivoted on a pile pier; these were opened at stated intervals to allow the traffic to pass. The rest of the bridge site was on dry land, and some of the well curbs were taken out, riveted up, and pitched. The river at this time was flowing in two nearly equal channels, about $\frac{3}{4}$ mile apart, and it was proposed to close the left channel, and to force the whole river through a channel about $\frac{1}{2}$ mile in width. The left training-bund was then set out and the earth-work was started, the distance between the bunds being the length of the bridge. The left training-bund was constructed, and the pitching was well in hand before an attempt was made, which proved unsuccessful, to close the left channel. The season's work terminated early in June, 1899, and the progress up to that time was:—Well-sinking, 0·51; concrete hearting, 0·21; stone pitching, 0·87, of which 0·25 had been done before the season's work was commenced.

The effect of the unsuccessful attempt to close the left channel the preceding season was to make this the main river as the rainy season advanced. Masonry-work and well-sinking were completed during this season, and the girder-work was started and completed between February and July. The training-works were started in January to bring the river back to the bridge-channel. As the river fell, the flow through the bridge channel steadily diminished, and in the middle of March this channel was absolutely dry. By the end of the season the bridge proper had been finished and also the season's programme for the training-works. During the rains of 1900 there was nothing to be done beyond the upkeep of the training-works, which were severely tried as the river rose in flood. These works were highly successful, and in October the left channel was finally closed.

The next season's work was short, as all that remained to be done was to throw up the main bank across the left channel. The

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bridge was tested in February, and was opened for traffic on 1 April, 1901.

The final quantities are:—

Well-sinking	875·30 lineal feet.
Masonry in lime	386,870 cubic feet.
Masonry in cement	17,895 „ „
Concrete	50,399 „ „
Girder-work	1,699 tons.
Stone-pitching	1,827,000 cubic feet.

Materials.—The bricks used measured 9 inches by 4½ inches by 3 inches. The earth for making them was not very good, the bricks although hard were not shapely, and the work had to be carefully pointed at the finish to make it look well. The brick-making season in Bengal is short, as most of the country is under water between June and December.

In mixing the mortar various proportions of the ingredients were tried, and the best result was obtained with a mixture of 1 of white lime, 1 of kunkur-lime, 2 of sand and 2 of powdered brick, all measured by bulk. The white lime was sent up, in its burnt state, from Calcutta in bags. It was a good strong lime, and could stand 3 parts of sand. The kunkur-lime was made from nodules of kunkur, which were carried 150 miles by rail from across the Ganges, and were burnt in circular perpetual kilns on the works. There were six of these kilns, in three buildings, each containing two kilns built together. They were 18 feet in height, giving a chamber 4 feet in diameter at the top and bottom, and widening out to 8 feet in diameter at the middle. They were fed from the top by means of a staircase, and the burnt kunkur was raked out below. The proper proportions were a 6-inch layer of gravel, and a 2-inch or a 2½-inch layer of slack coal. Each double kiln produced 60 cubic feet of lime per day. The kunkur-lime thus prepared was much cheaper than the white lime, but would not bear a greater proportion of foreign matter than 1 to 1. Sand was at first brought by rail from a distance, but later, as the well-sinking progressed, good sand was found about 40 feet below the river-bed. It was sharp and clear, and did not require to be screened. It was carried up to the mortar-mills by the returning trolleys. "Soorkee," or broken brick, acts as a pozzuolana; the brick used must be hard but not vitrified. There were four mortar-pans in the mortar-shed, each 7 feet in diameter. They were ranged in pairs, and could be driven all four together or singly as required. They were driven by a 20-HP. engine, with an 8-HP. portable engine in reserve in case of

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accident. One of the pans had a slotted bottom, and was used exclusively for the making of soorkee. The soorkee from this pan had to be fine-ground in another pan, and then finally screened before it was used in the mortar. The slotted pan could coarse-grind as much as the other three pans, and the little extra grinding did not take much time; the use of this type of pan was therefore distinctly advantageous. The other three pans were used for mixing the mortar, and when not required for this purpose they were available for soorkee-grinding. The lime-kilns and the mortar-mill shed were close together and on one of the sidings. The mortar was mixed wet at the mills, and was sent down to the work on the trolleys. The arrangements were sufficient to allow of 2,500 cubic feet of masonry and 200 cubic feet or 300 cubic feet of concrete being made daily. The mortar so made was strongly hydraulic and set in 24 hours. When it became necessary at the commencement of the second season's work to dismantle some of the masonry which had been built some months, it was found that the mortar was as strong as the bricks, the brick frequently being fractured before the mortar-joint parted. Great care was taken to soak the bricks well for several hours before use, and to keep the mortar wet until it had set.

All the fourteen piers were exactly the same, with the exception of the abutment-piers, which had ballast-walls. The space between the inner and outer faces of the well-curb having been filled with concrete, the masonry was started on this, flush with the outer face of the well-curb, and was gradually corbelled on the inner side from a thickness of 1 foot 9 inches on the top of the curb to 7 feet 6 inches, the corbel being half the thickness of a brick. This great thickness of 7 feet 6 inches was given in order to help the well to sink quickly. The depth of the well in the finished foundation was 60 feet. At a distance of 7 feet 3 inches from the top course of the well the masonry began to corbel outwards for twenty-nine courses, in order to give the proper length for the pier. From a diameter of 24 feet 6 inches the cross-section of the well was developed into an ellipse 24 feet 6 inches in width and 30 feet 6¼ inches in length, and the pier was built on this. The pier was 10 feet 5 inches in width and 30 feet 5 inches in length, with semi-circular ends. There was no batter on the sides or noses of the piers. For 4 feet at the top the masonry was brick in cement in four courses, each projecting 2½ inches. The mortar for this was 1 of cement to 3 of clean sand The girder bearings rested on bedstones measuring 4 feet

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6 inches by 4 feet by 1 foot 6 inches. These stones had to be brought a great distance by rail, and were costly. The top of the pier was flush throughout.

Concrete was made of broken hard brick, sufficient mortar being added to fill the interstices. A plug of 3,000 cubic feet was placed in the bottom of each well by means of a skip let into the water. This quantity was sufficient to fill the well to the height at which the inner corbelling stopped. The well was filled with clean sand, and a top plug of concrete, 5 feet in depth, was put in.

Well-Sinking.—The well curbs were circular and 24 feet 6 inches in diameter. The outer plate was vertical, and the inner plate was inclined to it at an angle of 30°. The curbs were in four pieces, and were taken out to the site before they were riveted up. Six tie-rods, 1½ inch in diameter, were riveted to gussets between the inner and outer plates. These rods were 15 feet in length and were screwed at the top. When the masonry had got up so far, six bond-plates, 5 inches in width by ¾ inch in thickness, were screwed down to the masonry by the rods. There were four sets of these tie-rods and bond-plates, so that the whole masonry of the well was fastened to the well curb. The curb was riveted up and properly centred, and then the spaces between the curb plates were filled with concrete. The curb was then sunk by coolies, who dug away the material from the inside of the well until the top of the curb was down to ground level. The first 15-foot length of the masonry was then built, and the bond-plates were screwed down. The well was allowed to rest for a day or two until the mortar had begun to set. Four heavy plumb-bobs were suspended from the top of the well, and these were carefully observed in order to see that the well did not get out of the vertical as the work proceeded. If any list was noticed the dredger was hauled in to dig at the higher side, and the well soon came straight again. With 7 feet 6 inches thickness of lining, the hole in the well was 9 feet 6 inches in diameter. For the first few wells the first length was usually sunk by means of small hand-dredgers. One or two of these were used; they were suspended from shears, and were hauled up by means of crab winches. When it was eventually found that the material was pure sand, and there was not much danger of the well getting hung up, large dredging-tackle was employed, and a whole 15-foot length has been sunk in a day. Several shapes and sizes of dredgers were used; that which gave the best result was a Bruce dredger, which lifted 20 cubic feet. The dredger was swung from a tripod of 30-foot poles resting on the top of the masonry, and the material was removed by a trolley

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on a pair of rails laid across the well. The dredger worked well when driven by a 5-ton steam-winch by means of a flexible steel rope. The dredger could easily bring up as much as a gang of twenty men could clear away. The material was, as a rule, clear sand. Rates of sinking of 6 feet to 7 feet per day were common. The sinking of the corbelled portion on the top length of the wells was slow and difficult, and dredgers had to be used on the outside as well as inside. Some of the wells got hung up by the corbels, and the joints opened out. When this happened pumps were applied, and the cracked corbels were chipped away, leaving a ring on the outer side about one brick in thickness to act as a cofferdam. The joints were caulked, and in the course of time the first course of the corbel was reached, and fresh masonry in cement mortar was built on the top. This had to be built inside the outer skin, and consequently it had to be built about 1 foot 6 inches higher, in order to get the desired length. Only one well gave serious trouble; this was at the right abutment, where a stiff clay formation was met with; the well got hung up, and when it did go down it was somewhat out of line. Powerful jacks were applied against timbers resting on the sides of the well and on the founds. One or two 10-ton Weston differential pulley-blocks were used to pull upon ropes fastened around the well, and men were posted on the pulley-chains to keep these agitated whilst the dredger was at work. By these means most of the cant was in time taken out.

Girder Erection.—The girders are of steel, 156 feet 8 inches centre to centre of bearings, with the road on the bottom boom. A complete girder with knuckles weighed 159 tons. The top booms were in four pieces, and the bottom booms in five pieces. The greatest weight to be lifted was 2½ tons. One bearing is fixed and the other is on rollers, and on any individual pier the bearings are all of the same kind. The fixed bearings were fastened to the bedstones by means of leaded Lewis-bolts, and the foundation of the roller-bearings was secured by liquid cement poured into the Lewis-bolt holes. The piers being only 24 feet in height, the staging consisted of trestles 16 feet in depth, resting on sleeper-stacks or bags of sand. The complete staging for a span consisted of a trestle resting on a sleeper-stack on each well, and fastened to the piers. Two trestles in the middle of the span were braced together. Two spans of old 60-foot girders were hoisted upon these. Over them metre-gauge rails were placed 2 feet 6 inches apart, and a floor of old sleepers was laid on the top. Neither the rails nor the sleepers were fastened in any way to the 60-foot girders. Each single 60-foot girder weighed 7 tons, and was lifted by a winch

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and tackle at each end. Some of the 60-foot girders showed a tendency to buckle, and had to be braced together. The strain put upon them by the jacks when putting in the camber also tried them severely; in some cases subsidiary trestles had to be put in the middle of the 60-foot span to strengthen it. Over the water-spans the trestles rested on clusters of piles. The girders were erected in some of the spans before the masonry had been built, and the trestles were then supported by rakers both length-wise and cross-wise. There were sufficient tools to allow of three spans being erected at one time, and this proved sufficient, as the whole of the girders were erected before the rainy season set in.

The Main Training-Bunds.—The right training-bund extends 1,900 feet up-stream and 400 feet down-stream from the south abutment. The right bank of the river was dressed to a slope of 2 to 1, and a bund 10 feet in width was constructed on the top of it to a height of 3 feet above high flood-level. The whole of the outer slope was covered with rubble stone to a thickness of 2 feet, with extra thickness at the top of the slope. The up-stream portion of this bund was inclined to the centre-line across the bridge at an angle a little less than 90°; the down-stream end was laid out to a radius of 400 feet. Both heads, up-stream and down-stream, were ultimately dug out to low-water level, and were filled with stone, 75,000 cubic feet being used at each head. The left training-bund extends from the north abutment; it was set out to form a *vena contracta* with the right training-bund up-stream, and the down-stream portion was curved off as in the right bund. It has a width at the top of 10 feet, slopes 2 to 1, and the materials for its construction were dug from the bridge channel. The stone train was run along the toe of the slope, and the stone was thrown with one handling. Owing to the failure of the attempt to close the left channel, this bund had a season's rest before coming into use. There was no current on it during the rains of 1899, and a quantity of rich silt was brought down, which encouraged the growth of grass, etc., amongst the stone pitching, and so helped materially to increase its power to resist erosion. It was found on these works that stone pitching alone gives little or no protection to banks made of sand, and that a coating of brick ballast, 1 foot in thickness, overlaid by stone, will protect a sandbank against a considerable quantity of scour. Each well when finished had 7,000 cubic feet of stone laid around it in the form of a ring 20 feet in width and 2 feet to 3 feet in depth. Before laying this stone the earth was dug down to low-water level, and then any brick-bats available were spread, and the stone was laid over them.

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The Training-Works.

The state of the river when work was commenced on the bridge is shown in Fig. 1, Plate 11. It will be seen that the river at the bridge site was divided into two nearly equal channels, which separated about ¾ mile up-stream and united about the same distance down-stream. The general scheme was to close the north or left channel, and to train the river through the right channel. The right bund was completed before the bridge works were started; the left bund was completely thrown up and the pitching was well in hand before an attempt was made to close the left channel, in April, 1899. The site chosen was on the centre-line of the railway. An apron of stone, 200 feet by 20 feet, by 2 feet in thickness, was laid in the middle of the channel. The river in this channel was 500 feet in width and 6 feet 3 inches in depth at the deepest part; the maximum velocity was 2·5 feet per second, and the discharge was 3,700 cubic feet per second. A bund of earth, bags, and stones was run out from each bank. The river bed was of loose sand, and it was found as the work progressed that the bed was torn up as fast as the materials were put in. The effect of the works was to convert the river into a roaring torrent which could be heard 2 miles off. By the middle of May, when the work seemed to be gaining on the scour, the river had begun to rise in flood owing to the melting of the snows in the upper parts of its course, and all hope of closing the gap had to be abandoned. The head on the works was as much as 3 feet 9 inches, whereas the difference in level between the head and tail of the bridge island was only 1 foot 4 inches. It would be interesting to know how so much additional head was developed. When the head was 3 feet 7 inches there was no perceptible current in the cross channel, ¾ mile up-stream, connecting the left channel and the bridge channel; at the same time there was great sympathy between the channels, as a rise or fall of head at the works was at once noticed at the bridge channel. Whilst this work was in hand another bund was started higher up the river, and, aided by the backing up of the water due to the lower bund, made good progress, but when the lower bund was carried away the upper one was soon so badly damaged that all works had to be stopped for the season. These works used up 150,000 cubic feet of stone and 70,000 bags of earth, and cost about 60,000 rupees. From the experience acquired later, on these works, the main causes of the failure to close the left channel were found to

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be: 1. The site was badly chosen, as it was in a *cul de sac*, ¾ mile below the parting of the channels. It is probable that the extra head encountered was due to the energy of the flowing water being somehow converted into potential energy. Had the site been at the parting of the channels the head would have been much less. 2. The flooring of stone was not sufficient to prevent scour, as the river bed was of pure sand. A mattress covered with stones would have stopped all scour on the central portion of the channel whilst the works were in progress at each end. The works confined the left channel, and induced a scour of 40 feet in depth. During the ensuing monsoon the flow steadily increased down this channel and diminished in the bridge channel. In March, 1900, when the river was at its lowest, it was possible to walk dry-shod right across the bridge channel.

During the rains of 1899 several projects were put forward to deal with what was then seen to be a serious undertaking, namely, the closing of the left channel. One project was to run simultaneously three bunds made of bags of earth, so as to divide the head amongst them, and then to concentrate the labour and to close one of the three bunds. Another proposal was to make a pile bridge with a wide roadway on top, to collect sufficient bags of earth on this, and then to throw them all in on a certain day. This method had succeeded in smaller works of the same kind, but it was felt that in the present case the work was much too large to be accomplished in this way. It should be stated that stone was costly and so difficult to obtain in quantity that it could only be sparingly used; otherwise, with abundance of rubble-stone, it is only a question of time and labour to close a flowing channel. These schemes had the disadvantage that in the event of their failure the state of affairs would be no better than before, and another season's work would be lost. It was finally decided to carry out the works now to be described. At the worst, it was reasoned, they would tend to change the current, and if not successful in one season's work there would be so much done at the beginning of the next season. The state of the river after the rains of 1899 is shown in Fig. 2, Plate 11. It will be noticed that the river had left the bridge channel and was practically all flowing through the left channel. The training-works were situated about ½ mile up-stream. The intention was to train the river gradually, and not to attempt to close the left channel. The works comprised:—

(1) A bund run out from the north side of the left channel at an angle of about 45° and heavily pitched with stone.

(2) A line of piles working out from the opposite bank.

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(3) A protecting bund from the end of the line of piles to the left main training-bund.

(4) The water-cut.

(1) *The Bund from the North Side of the Left Channel.*—The object of the bund was to give the river a set towards the water-cut. The bund was constructed in flowing water having a velocity as high as 6 feet per second, and a depth up to 20 feet. For the first 50 feet out from the bank there was little velocity and consequently little scour. As soon as scour began to develop, a double wall of bamboo stakes was driven into the river bed at the calculated toes of the slope of the finished bund. These walls were 5 feet apart at the bank, widening out to 10 feet apart as the depth of water increased. The bamboos were 3 inches in diameter, and were pointed and driven in 6 inches apart, their heads being sawn off about 2 feet above water level. They were tied by country rope to longitudinal and cross horizontal bamboos, and the space between the walls was filled with bundles of long grass cut from the river banks. A stack of these was built between two of the bamboo walls; this was loaded with earth until it sank to water-level, then another stack was built on top, and so on until the grass was driven right down to the river bed. These walls were kept about 50 feet ahead of the earth filling, and the earth was consequently thrown in still water and did not scour. In order to stop all scour in the river bed, broken bricks were thrown along the site of the up-stream bamboo and grass wall, to about 10 feet in width and 1 foot in depth. This pitching was kept 50 feet ahead of the bamboo walls and consequently 100 feet ahead of the earth filling. It was found that the current along the up-stream wall increased as the work advanced, and in order to throw this off, little cross-bunds were made at intervals of 50 feet. These were inclined at an angle of 45° to the main bund, and were consequently perpendicular to the left bank of the river. They were 20 feet in length and upwards. They consisted of a double wall of bamboos and grass, and later on were heavily covered with stone. They acted like the blades of a turbine and stopped the current along the bund. Their utility has been questioned, but they were found exceedingly effective. The first 400 feet or 500 feet in length was done by coolies with baskets; afterwards rails were laid and trolleys were used. The rails at the tips rested on beams; the outer ends of these were supported on a large boat resting between the up-stream and down-stream walls; this was pulled out as required. As the load further increased, trolleys had

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to be replaced by a small engine and trucks. Working in this way, a total length of 1,000 feet of bund was constructed in 5 months' time in a sandy river-bed where in places 20 feet depth of water, flowing with a velocity of 6 feet per second, had to be contended against. The last 50 feet of the bund was made into a solid mass of stone resting on a mattress and sloping up to the top of the bund with a slope of 1 in 5. The bund was 10 feet in width at the top, with slopes of 2 to 1, and was 3 feet above flood level. The up-stream face was heavily pitched with stone, and the down-stream face was covered with bags of earth for the first half of its length, and with brick pitching for the remainder. This bund gave no trouble whatever when the river rose in flood. A reserve of stone was stacked at its commencement, but it was not required.

(2) *The Line of Piles.*—This was intended to head up the water and obstruct its flow down the left channel, at the same time giving increased velocity of flow down the water-cut. The beginning of the pile work was 300 feet down-stream in the direction of the length of the bund, and it was made at an angle to the bund so that there was a space of 150 feet left for the boat traffic. The piles were upwards of 20 feet in length and were driven at least 10 feet into the river-bed. There were three rows of piles driven so as to break joint, lines joining the heads forming equilateral triangles of 4 feet side. The piles were driven in by hand pile-drivers, which were dragged along the river bed in shallow water and were placed on boats where the water was deep. The piles were scarfed, and another set was placed on top of them, rising 3 feet above high flood-level. Each group of three piles was connected together at the top by distance-pieces and 1-inch bolts. The river bed near the piles was protected from scour by means of a mattress 20 feet in width on the up-stream side and 40 feet in width on the down-stream side, extending the whole length of the piling. The mattress was loaded with 2 feet thickness of stone. It was made *in situ* on stakes driven into the river bed, and was continuous, the work of lowering and pitching proceeding steadily from one end. The 150-foot gap between the bund and the piles was not protected from scour, and at one time the water in it was over 30 feet in depth. The line of piles was 500 feet in length; it suffered severely during the monsoon and ultimately only about half of it was left. As occasion offered, gaps were made up by placing a double line of rails in position. The feet of the rails were 6 feet to 10 feet apart and were weighted where possible; the heads were brought together in pairs, and the whole line of pairs had an

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old wire rope lashed to it, thus giving a certain amount of play. These rails acted well, as they threaded up the water and caught large quantities of grass and drift.

(3) *The Protecting Bund.*—The protecting bund completed the line of defence between the piles and the bridge. It was thrown up to 3 feet above high flood-level and was pitched with stone down to low-water level. The top was 10 feet in width and the slopes on each side were 2 to 1; it started from a point 300 feet from the end of the left main training-bund, so as not to form a re-entrant angle, and ran right into the pile-work. Large reserves of stone were kept ready at the most exposed places. On one occasion the bank of pure sand subsided bodily, and the river began to flow over it. This part of the training-works had to be carefully watched when the river was high, as the material forming it was mostly pure sand.

(4) *The Water Cut.*—Whilst all the works described in the foregoing were in progress, a canal was cut from the up-stream side of the training-works to a point below the bridge, from which there was a steady fall to the left channel. This canal was made to allow the headed-up water to escape into the bridge channel. It was nearly $\frac{3}{4}$ mile in length, nowhere less than 200 feet in width, and in places as much as 7 feet in depth. As far as possible, the earth excavated from it was thrown outside the bridge channel. The whole of the training-works were finished by the end of May. The estimated cost was 2,26,145 rupees. The protection-works to the main bank and left training-bund contain 16,000 cubic feet of stone and 50,000 cubic feet of fused brick. These works were necessary to protect the main bank, which had been thrown up at the north end of the bridge, during the rains, after the failure to close the left channel in May 1899.

The following are the quantities of materials employed in the training-works:—

Earthwork in bunds	1,268,000 cubic feet.
Brick pitching	97,500 „ „
Stone pitching	727,200 „ „
Bag work	180,000 bags.
Mattress work	30,000 square feet.
Piling	15,000 lineal „
Water-cut	4,000,000 cubic „

In June the river came down in flood and the head on the works rose to 2 feet 7½ inches; the pile-work was severely tried, as floating logs frequently struck it, but none of the piles were carried away, and when the flood subsided more stone pitching was laid

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along the foot of the piles. When the river was low the current was through the opening left between the bund and the piles. This portion, which was not floored, began to scour. As the river rose in flood the current was carried further out and the unfloored portion began to silt up. Later on, the portion of the works near the root of the line of piles was swept away and was replaced by rails tied together in pairs. More than half of the piles in the upper row were carried away during the progress of the rains. During the month of June the main current was down the left channel, and drift-wood and dead cattle were carried that way in flood times. In July the current gradually changed over to the bridge channel. Early in August there was fully twice as much water passing under the bridge; the water-cut had scoured to 20 feet in depth and had eroded its sides considerably. Towards the middle of September the river began to fall, and the 150-foot gap between the bund and the piles was gradually filled up with trees weighted with bags of bricks. Had this not been done, the opening would have scoured out again. By the end of October a solid bund was thrown right across the down-stream side of the training-works. This bund was closed on a carpet, measuring 100 feet by 50 feet, made of the commonest country cloth. Strips of bamboo were tied to the cloth at intervals to keep it from rising when in the river, and it was weighted with bags of sand. The two ends of the bund working in from both sides gradually closed on this carpet. The core of the bund consisted of a wall of bamboo and grass, and the bamboos were driven through the carpet into the river bed. The river was thus finally shut out from the left channel. The trouble, however, was still not quite over. A tributary of the Teesta, called the *mora* Teesta or dead Teesta, which flowed into the left channel below the training-works, with a discharge in the cold weather of about 50 cubic feet per second, still continued to flow down the left channel after the main river had been finally diverted. Whilst the works already described were under construction, arrangements were made to complete the line across the left channel. Sidings were laid to bring earth by train. A temporary line was thrown up by coolies, crossing a pile bridge, 200 feet in length, in the middle of the channel. Alongside the bridge the bed of the river was covered with mattresses weighted with bags of sand, and the 200-foot opening was gradually closed. When it was nearly closed, only a 50-foot opening remaining, the bund already thrown across the training-works was opened, to allow the waters of the *mora* Teesta to escape, and the closing of the left channel was then completed, the water of the *mora* Teesta

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finding its way up-stream, as it were, through the training-works. A month's work by train completed the main bank, which was then planted with coarse grass. During the cold weather of 1900–1901 the water-cut became the main channel and all the boat traffic passed that way. When the left channel had been finally closed, all the stone was taken off the training-works and protecting bank, and solid stone heads, up-stream and down-stream, were built to each of the training-bunds; each head contained 75,000 cubic feet of stone, and the rest of the stone was stacked at convenient places as a reserve in case of need.

As the bridge has had one season's rain through it, it may be assumed that the river has now settled down in the new course provided for it.

The Paper is accompanied by four tracings, from which Plate 11 has been prepared; and by an album of photographs which may be seen in the Institution library.

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(Paper No. 3353.)

"Reclamation of Drift-sands in Cape Colony."

By CHARLES DIMOND HORATIO BRAINE.

WITHIN comparatively recent years the attention of the Government has been directed to several extensive regions of drift-sands in various parts of the Cape Colony. This has resulted from the devastation of land, the threatened destruction of towns and villages, the obstruction of traffic by obliteration of roads, and, in the case of Port Elizabeth, from the increased difficulties of dealing with the problem of harbour-works.

The first organized attempt at reclamation was made about 60 years ago on the Cape Flats, near Cape Town, a sandy district of about 20 miles in length and 12 miles in breadth. Many square miles of this area consisted of shifting sands, which involved constant expenditure in maintenance of the roads. When the "hard road" through the Cape Flats was completed, it was ascertained that the encroachment of the sands in certain places was so considerable that, unless it could be arrested, the road would soon present its former obstacles, and become, in some parts, quite impassable. At one time 1½ mile of the roadway was covered with deep sand, and the Road Board suggested that the most effectual method was to bind the sand with vegetation. In 1876 Mr. Hawgood, in a memorandum on these drift-sands, stated that they draw their supply from False Bay, where the sea at ebb-tide leaves on the beach a portion of the sand carried in suspension. Before the next high-tide a part of this deposit becomes dry, and is blown inshore by the south-east winds. Upon meeting an obstruction the sand piles up, forming itself into immense waves, which are rolled across the country by the action of the wind, entombing everything in their path. All the waves have a similar configuration, the side presented to the wind having in no case a steeper slope than 2 to 1, the crest being almost horizontal for a width of 1½ yard, and the leeward side taking a slope of about 1 to 1.

The first system adopted was to construct near the road two

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long, nearly parallel screens, about 12 feet in height and 484 yards apart, and to plant the enclosed sands with Hottentot Figs (*Mesembryanthemum edule*). The results were most successful, and the official Report states: "The whole of the land then unreclaimed, including the sand-hills formed by the accumulation of the screens, has been planted, and instead of an arid desert of about 2,000 acres, which was formerly one waste of sand, the drift of which across the road was so cutting that it was painful even to travel, has been converted into a perfect garden."

However effective the Hottentot Fig may be as a sand-arrester, it was soon realized that, by forming plantations of useful trees and timber, while attaining the object of binding the sands, reclamation might be made to return some interest on the outlay. It was found that there were no indigenous productions in the Colony suitable for this object, and different varieties of Australian trees were substituted. Those found most successful were the *Acacia saligna* and *Acacia cyclopis*. The *Hakea*, *Fabricia*, and *Callitris* were also introduced as being good sand-plants; but although they grow freely, making good hedges and wind-breaks, they are of no economic value. During the succeeding 35 years much valuable work was done, and an improved system of reclamation gradually evolved. The screens had been reduced to a height of 3 feet or 4 feet, with a distance apart of about 8 feet, and were run at right angles to the prevailing winds. They were formed of bush, the stems of each branch being planted separately in the ground to a depth of at least 1 foot, and the sand was well rammed or pressed round it. With the object of disturbing the sand as little as possible, crowbars were used in preference to spades. The screens were sufficiently thick and compact to act effectively as wind-breaks, and most of them were put in by contract, at about 1*d.* per lineal yard. The best bush for the purpose is that which retains its leaves longest after becoming dry. Between the rows of screens, seeds of different trees and grasses were sown and raked in. The rule was to work with the wind, from the back or commencement of a drift, and never against it. In 1876 Mr. J. S. Lister, who was in charge of the drift-sands at Kuil River, on the Cape Flats, proposed that the street-sweepings and refuse from Cape Town should be utilized for the purposes of reclamation. His suggestion was adopted by the Government, and the result proved highly successful—the artificial nourishment causing the plantations to grow with marvellous rapidity. In 8 years a return was obtained from posts, bark, and firewood; in 11 years the sands which threatened

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the railway-line near Durban Road Station had been arrested, and hundreds of acres had been converted into a valuable property covered with plantations of trees.

Besides the Cape Flats, there are several other areas of drift-sands in the Colony, the most important being near Port Elizabeth. These extend in a north-easterly direction, from a point on the coast of the Indian Ocean, known locally as the "Gulchways," across the base of Cape Recife, and empty into Algoa Bay at the Fisheries, *Fig. 1*. The distance is about 11 miles, and in 1883 it was estimated that there were some 18 square miles of sand. This area was being steadily increased; and in 1890 there was an unbroken stretch of moving sands, about 14,560 acres, or over 22 square miles in extent. These rolling waves of sand had destroyed nearly every vestige of tree, shrub, and grass in their path, and not only that, but in many places the attrition by the driven sand had worn away the surface of the ground down to the limestone formation. This process of destruction is still going on, and it is no uncommon thing to see benches of the original soil 3 feet in height, forcibly demonstrating the denudation that has taken place. It is a popular idea that the trouble originated, and developed into its alarming conditions, during the first 80 years of the last century; but the evidence to support this is by no means convincing. In the latter part of the 18th century this region of South Africa was practically unexplored. Algoa Bay was visited in 1798 by Mr. (afterwards Sir) J. Barrow, who spent several days in examining the surrounding country, and with prophetic foresight predicted its future as a successful seat of commerce. No mention is made by him of these drift-sands, but extensive sands along the shores of the bay are shown on a chart prepared by Lieutenant W. M. Rice, R.N., at that time. On a diagram of Buffelsfontein, as surveyed in 1815, there appear the two notes: "Thicket to the sea-shore," and "Sand and shrubbery to the sea-shore." The former refers to the part now known as the Gulchways—the site of the commencement of the drift—and the latter refers to another part of the existing sand-hills. The earliest mention of these sands that the Author has been able to discover is an ordinance in the Government Gazette, dated 5 October, 1826, imposing a fine of £2 to £5 on any one "who shall cut, etc., any bushes or brushwood on the waste lands lying along the coast of Port Elizabeth." This was "to prevent the loosening and drifting of the sand over the adjacent country." It is evident from this that the trouble was in existence previously to 1826, and had by that time assumed such proportions that the

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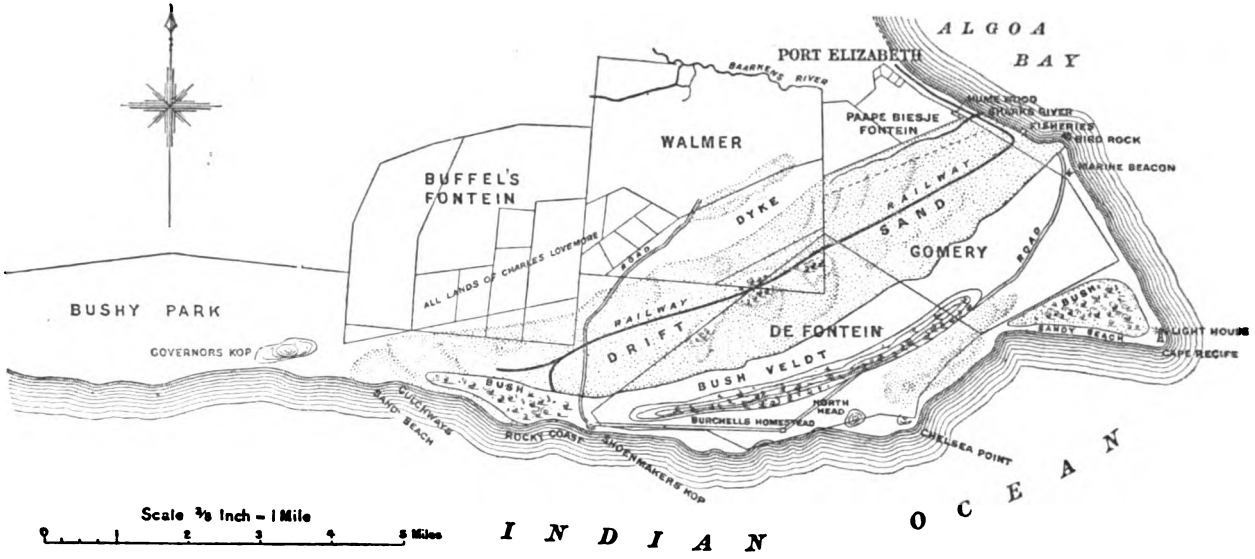
Fig. 1.


ALGOA BAY
PORT ELIZABETH
BAARKENS RIVER
PAAPE BIESJE FONTEIN
WALMER
BUFFEL'S FONTEIN
ALL LANDS OF CHARLES LOVEMORE
FEED
DYKE
RAILWAY
SAND
GOMERY
ROAD
BUSHY PARK
GOVERNORS KOP
RAILWAY
DRIFT
DE FONTEIN
BUSH VELDT
BUSH
QUICKWAYS
RAMP BEACH
ROCKY COAST
SHOENMAKERS KOP
BURCHELLS HOMESTEAD
NORTH HEAD
CHELSEA POINT
SANDY BEACH
LIGHT HOUSE
CAPE RECIFE
MARINE BEACON
RIGG ROCK
FISHERIES
SHARKS RIVER
Scale ⅜ Inch = 1 Mile
0 1 2 3 4 5 Miles
INDIAN OCEAN

Government realized the danger of the sands spreading, and the necessity for prohibiting such action as would tend to aggravate the evil. It would be interesting to know what were the circumstances which gave rise to this ordinance, but a diligent search among the archives failed to discover any other information than that the ordinance had been passed. Various reasons have been assigned for the origin of the sands; *e.g.*, veldt fires, the cutting of firewood, vegetation being trampled out by stock, and cattle breaking up the ground with their horns. Bush-cutting could scarcely have been the cause, for in April, 1820, the population of Port Elizabeth was only thirty-five persons, including the garrison. These inhabited two stone-built houses and a few huts. In the same year 4,659 settlers landed from emigrant ships in Algoa Bay, and, according to one tradition, it was due to their reckless bush-cutting that the drift-sands originated. The climatic conditions, however, are such that very little fuel is required except for cooking purposes, and it is improbable that they should have gone over 12 miles for their wood. Besides this, they did not permanently increase the population, as they were soon dispersed to various parts of the Colony. It is said that some years ago there were old men in Port Elizabeth who remembered when there were no drift-sands there, but such information by untrained and unscientific persons is, of course, unreliable. An officer of the Forest Department accepts the popular tradition, and in a Report states: "It is an appalling fact that within the last 100 years, in the neighbourhood of a prosperous town, upwards of 22 square miles of what was a fertile and well-wooded country has become a desert." If this is true the rate of travel of the sand must have been phenomenal, and the assertion is in no way borne out by recent observations. The distance from the Gulchways to the Fisheries is approximately 11 miles, and for the sands to have covered this distance in 80 years they must have travelled at the rate of 726 feet a year. With an annual travel of 100 feet they would have taken 580 years. There is, on the other hand, abundant evidence to prove that these sands must have been in existence for hundreds of years, and, moreover, that there must have been at least two cycles of natural reclamation, each followed by a period of resuscitation of the drifting sands which entirely destroyed the vegetation. The area over which these changes extended has not been under observation; but in the very heart of the dunes are ridges of sand which evidently were once covered with vegetation for a period sufficiently long to cause the formation of soil. This

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is covered with another layer of sand, and superimposed on that is a second layer of soil, on which, in a few isolated places, there is still a natural growth. A somewhat similar formation is seen on the shores of Algoa Bay. That these periods must have been of very considerable duration is evident from the fact that the layers of soil are not less than 1 foot in thickness, and the amount of soil formed under trees of 10 years' growth is practically nil. Two additional proofs of the remoteness of the origin of these dunes are found in (1) the sheet of limestone spread between the sands and the underlying quartzite formation, and (2) the existence of numerous sand-castings of stems or branches of former tree-growth. The latter are doubtless formed by accretions of calcareous deposit on the surface of the wood, which, after the decay of the vegetable tissues, formed moulds. These, when filled with sand and cemented with lime, have formed solid structureless castings. Fossils of a similar nature are found in the dunes near Cape Town, and under those sands, as at Port Elizabeth, exists a limestone deposit. In the annual Report of the Geological Commission for 1897, Professor Corstorphine gives the following account of the Cape Flats:—

"Various interesting features are presented by these dunes. The loose surface sand is continually shifting, thus gradually covering areas more and more remote from the sea; but the deeper portions, and in some places the entire mass of the dunes, have been converted into a more or less compact sandstone or limestone. This result has been attained by percolating water dissolving in its passage through the loose sand of the dune portions of the numerous shells and shell fragments. The carbonate of lime having been precipitated as the water evaporated, it in due course formed the cement which binds the once incoherent mass firmly together. In many places this deposition of dissolved shell material has gone on to such an extent that the resulting rock is really a limestone. At Saldanha Bay the rock is compact enough to be quarried and used as building stone, the new Museum and Post-office, Cape Town, having both been built of it."

The country to the south of Port Elizabeth is very sandy—in some places almost pure sand—but, except on the belt of sand-dunes, is everywhere thickly covered with vegetation, and although indiscriminate wood-cutting may have caused isolated drifts, which would account for many bare places outside the present area entirely devoid of any covering of either sand or soil, it can scarcely have been the origin of the present sand-flow. The drift begins at the Gulchways, a series of small ravines

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running down the bluff which rises from a long sandy beach. Up these gulches the sands were blown on to the comparatively flat ground, about 150 feet above sea-level, and thence they started on their devastating course to Algoa Bay. As an inexhaustible supply of sand is being continually washed up on this beach, all that was necessary to start the sands across the country was to find a passage up the gulches. At one time there must have been an effective natural barrier, and this must have been destroyed by fire or some other cause. On the bare places between the sand-hills are still to be seen remains of old kitchen-middens which probably were inhabited by primitive Bushmen, who still used stone implements. These men must have camped there when the country was covered with bush, and the fires may have been due to them. The sands having once started, their progress was no doubt accelerated by wood-cutters and veldt fires, and the trouble further aggravated by wandering stock. It is a common custom among many coast farmers periodically to burn the veldt, under the mistaken notion that they are improving the grazing. It is possible that a series of detached drifts may have gradually become merged into one, but the Author has been unable to obtain any reliable information to support the idea. Except in so far as the Government notice of 1826 may have had some effect, matters were apparently allowed to take their natural course until the development of the country and the construction of railways increased the importance of Port Elizabeth as a harbour. About 1870 the sand began to pour into Algoa Bay, and tons of it were carried by the northerly set of the currents past the harbour-works. The first note of warning was struck by the late Sir John Coode (Past-President Inst. C.E.), who, in his Report on the harbour in 1870, stated: "It is to be apprehended that the sand proceeding from the great drift which has recently crossed the promontory at the Fisheries to the northward of Beacon Point may increase the quantity (of sand) so conveyed along the coast." At that time there was a thriving farm at the Fisheries, which, about 6 years later, was completely destroyed, the buildings being buried by the advancing sands. Sir J. Coode in 1877, and Mr. E. E. Sawyer, M.A., M. Inst. C.E., in 1890, again called attention to the supply that was pouring from the drift into the bay. In 1897 Messrs. Coode, Son, and Matthews estimated that the increase of sand-travel, when the drift-sands were fully exposed to wind-action, was about 600,000 cubic yards per annum; and, in reporting on a new scheme of works, estimated that two pump-dredgers could control the accumulation of sand, but that after

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the planting of the sands had been completed one dredger would suffice. The annual cost of each dredger was estimated at £10,000. This amount capitalized at 4 per cent. would represent £250,000, which the Harbour Board could have been justified in spending on an effective system of reclamation.

The credit of attacking the drift and initiating the work of reclamation is due to the Harbour Commissioners of Port Elizabeth. By Act 20 of 1872 they were empowered to apply such sums of money from their revenues as might be necessary for the purpose of fixing the sands, and power was given them to purchase the lands affected. The Act also prohibits the uprooting of trees, bushes, and fibrous-rooted plants. The first attempt at controlling the drift was made in 1873, when the Board began operations at the Gulchways. Their main efforts were directed to the construction of an artificial dune along the beach, and—with the exception of about 2 years during which operations were suspended as a protest to the Government against using harbour revenues for this purpose—work was continued until 1893, when the Forest Department fortunately took over the reclamation of the whole drift. During these 18 years the Board had expended upwards of £32,000 on reclaiming about 950 acres, erecting fences and constructing a road. They had also succeeded in cutting off the ingress of the sand. The works had been visited from time to time by various persons who were thought likely to give practical advice, and in 1877 two sand-fixers were brought from France; but except for the work at the Gulchways nothing whatever was done to arrest the progress of the drift that was steadily advancing on Port Elizabeth. The cessation of operations for about 2 years led to deplorable consequences. Nothing was done to maintain the old work, and an important strip that had been planted and fixed above high-water level at the mouth of the fourth gulchway was destroyed. It is certainly a matter for regret that so much time, money, and labour were expended on a project of such magnitude without some definite plan for carrying out the work. This, from the first, should have been in the hands of a trained scientific Forest officer, and experiments with the plants best suited to the special conditions should have been carried out. But nothing of the sort was done, and in 1893 there was not much to show for 18 years' work. The plantations at the Gulchways were in a patchy condition, and the littoral dune was found to be too far from the beach to afford them safe protection. In addition to the work at the Gulchways, between 1876 and 1884 the Harbour Board spent £2,145 in reclaiming a small detached drift of about

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39 acres on the farm Paape Biesje Fontein, on the outskirts of the town. This drift very seriously interfered with the harbour-works, not only in carrying large quantities of sand into the quarry and so hindering the work there, but also by blocking the lines of tramway and destroying the working parts of the rolling-stock and machinery. It was spread with bush, and sown with various kinds of seeds, at an average cost of about £55 per acre.

In 1890 Mr. J. S. Lister, of the Forest Department, was called in to draw up a scheme for the systematic reclamation of the dunes. He recommended the adoption of the same system that he had introduced with such success on the Cape Flats in 1877, viz., that the town refuse should be utilized for spreading on the sands. This consisted of street-sweepings, contents of dustbins, kitchen garbage, stable litter, etc., that was being used for levelling up and making ground in various parts of Port Elizabeth. It was to be carried out by rail, and work was to be commenced from the Algoa Bay or lee side of the main drift, but each sand-hill was to be dealt with in turn from its windward side. Mr. Lister considered that there would be no danger of the work being buried whilst in progress, as between each wave there is an open space or valley devoid of sand. The important feature of this scheme was to check the progress of the drift with the least possible delay, and thus prevent the sand pouring into the harbour. Assuming that the bare places between the sand ridges covered one-third of the total area (14,560 acres), there would be about 9,700 acres actually to be fixed and planted. The supply of refuse available was estimated at 80 tons per day, which, at 40 tons per acre, would be sufficient to spread 2 acres per day, or 600 acres per annum. On this basis it was calculated that the work would be accomplished in about 16 years, and, as wattles mature in 10 or 12 years, it was believed that long before the sands were entirely reclaimed there would be a revenue accruing from the sections first planted. The suggestions were adopted, and work was commenced near the Fisheries in August, 1893. Before that time, in addition to the stream of sand emptying into the bay, a detached drift had started on Walmer commonage, and was extending towards Port Elizabeth threatening by its encroachments the very existence of the south end of that town. The system of working the reclamation to windward, which necessitates not only the construction, but the constant maintenance and raising of new bush-screens for each section of drift that is being planted, is at first sight open to criticism. But it was justified by the existing conditions, and doubly justified by the success that has been achieved. Walmer

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was a rising residential suburb, as also was Humewood, on the coast between the harbour-works and the drift-sands, while the town of Port Elizabeth was extending southwards, and much valuable property was in danger of being ingulfed in the sands. Had the work been commenced at the Gulchways, the sands would, during all the years required for their reclamation, have been pouring into the harbour, and more land would have been destroyed yearly in the immediate neighbourhood of a large and important town. All this was prevented, and by the end of 1897 —4 years after the work had been taken in hand by the Forest Department—the whole area along the bay had been reclaimed, thus entirely cutting off the sand, which for over 27 years had been drifting into the harbour in increasing quantities. Another point in favour of the system adopted is that the railway for conveying the refuse-trucks runs through the heart of the sands, and is built in sections as required. The reclamation being practically kept ahead of the rails, there is no expense for keeping the track clear of sand, while the refuse is delivered conveniently for economical distribution.

Part of the first work done by the Forest Department was the raising of another barrier along the beach, at the Gulchways, as close as possible to high-tide level. This consists of a bush screen which is systematically raised as the sand piles up on it. It is kept higher than the crest of the ridge, so as to prevent the sand blowing over. In 1894 the dune or barrier was 25 feet in height, and in September, 1901, it extended over 2 miles in length, with a maximum height of 42 feet, and a slope as steep as 28° on the sea-face. Efforts are being made to plant this face, but so far without satisfactory results, only a few patches of *Triticum junceum* having been obtained. Pypgrass (*Ehrharta gigantea*) will only grow on the lee side of this littoral dune, although it is growing almost into the sea at Algoa Bay. This barrier is maintained in good order, and the screens are raised as required at a cost of about £85 per annum. Two natives live on the spot, and only occasionally are extra hands required. The sand blown up from the beach is remarkably fine. At the present time there is an absolutely bare stretch of ground at the top of the bluff, between the gulch plantations and the western end of the shifting dunes. The area is very irregular, but is approximately 350 yards in width. Unfortunately no record exists of the date when the supply was cut off.

The method of working in practice on the Port Elizabeth sands is to sow broadcast—about 35 lbs. per acre—a mixture of seeds

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composed principally of *Acacia cyclopis* and *Acacia saligna*, with an addition of *Acacia pycnantha*, *Pinus halepensis*, rye, pypgrass, etc., and then to spread immediately a layer of refuse. Sunflower and lucerne seeds have also been used with very satisfactory results. Tomatoes and pumpkins grow freely, being self-sown with the refuse, and from areas spread with stable-sweepings a large crop of oat-hay is reaped annually. In 1895 some 4,000 bundles were harvested from the reclaimed sands, and about 8,000 bundles in 1896 and 1898, at a cost of a little over 1*d.* a bundle. The market-price would have been at least 6*d.* a bundle. During wet weather the refuse is spread about ½ inch thick, but in the dry season a thicker layer is necessary. Much also depends on the quality of the refuse. After a shower of rain fibrous stuff and straw are, as it were, rooted in the sand, but horse-droppings have a tendency to be blown away and scattered by dry winds, thus causing breaks in the work. The refuse is loaded into trucks at two tipping-stations in the town, and are run out by locomotives to the sands, where they are discharged. The material is then loaded into small side-tip wagons, and hauled by mules up light railways on to the sand-hills, where it is distributed by means of baskets. The labourers are convicts, and generally work in squads of five, carrying large double-handled baskets—each of the three inside men lifting the handles of a basket at either side. The light railway is 2 feet 6 inches gauge, with steel sleepers, and rails weighing 12 lbs. per yard. The wagons have a capacity of 23 cubic feet. Four mules will drag a train of six wagons up a gradient of 1 in 15. Oxen were first used, but it was found that four mules could do as much work as sixteen oxen. As the track is for purely temporary purposes it is roughly laid, the cost varying between about 3*s.* per 100 yards over level sand, and 40*s.* per 100 yards over rough stony ground between the hills. In connection with the reclamation the Forest Department has a nursery of several acres in extent, where seedlings, etc., are raised, not only for planting out on the sands, and filling up gaps and breaks in the areas already treated, but also for sale to the public. Those found most successful are *Tamarix*, *Pinus halepensis*, *Acacia saligna*, and *Cupressus macrocarpa*. According to the official returns, over 60,000 young trees and cuttings, on an average, have been planted annually on the sands during the last 5 years (1895–1899). Before work on a new section is commenced, protecting screens are erected to windward, to check the movement of the drift as well as to prevent sand from encroaching on the newly spread area and cutting up young seedlings. They are constructed of stakes inter-

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laced with brushwood, and have to be continuously raised, as any obstacle at once causes great accumulations of sand. A long, well-defined ridge is generally selected for these artificial barriers, one of which is 660 yards in length, and about 48 feet in height, while another is 570 yards in length, and 52 feet in height at the highest point. In addition to the refuse-work, a considerable area of sand at Port Elizabeth has been reclaimed by spreading bush and branches on the dunes. These are laid side by side, just touching, or slightly overlapping, with all the butt-ends pointing to windward, *i.e.*, towards the prevailing wind, the ends or stems of each row being covered by the tips of the branches of the back row. The sands are sown, the seeds are raked in, and then the branches are laid. The method is proving very effective on outlying dunes far from the railway, and where there is a suitable supply of brushwood, as at Walmer.

All drifting sands tend to move approximately at right angles to the prevailing wind. This, however, must not be taken as an invariable condition of every sand ridge, for wind eddies, as might be expected, considerably modify their form. Occasionally a spur develops on the lee side of a ridge, and, travelling with considerable rapidity, joins with the next, forming the shape of the letter H. In some instances they are crescent-shaped, and when this form is further developed large circular spaces are enclosed. At times sand can be seen blowing from the tops of some of the dunes, while others show no perceptible movement. Some of the largest accumulations on Port Elizabeth sands give the appearance of miniature mountains, with easy slopes, steep escarpments and even deep ravines. The configuration is always being altered, but in spite of this the general movement is continuous in the direction stated. The windward slope of a sand-hill in its natural state varies considerably, and is often fairly flat—even as flat as 4½°, but on the lee side the angle of slope may be taken as 30° to the horizontal. The steepest of those slopes that the Author has measured was 32°. At Port Elizabeth the creep of the sands is north-east, the prevailing winds being from the south-west. Between 1 November, 1897, and 31 October, 1898 (according to a return compiled for the harbour engineer), the wind blew for 183 days, or parts of days, between west and south, with a velocity of over 20 miles an hour, and on seventy-four other days, or parts of days, it blew between the same points with a less velocity, making a total of 257 days on which it blew from the same quarter. On seventy-eight of these days the velocity reached or exceeded 40 miles an hour. In addition to these, the winds from the west

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and north affect the sands, and these are the driest winds in this district. It is a common sight to see gardens and crops wilted with the hot north winds, and with the dry westerly winds the streets of Port Elizabeth are swept as if with a broom. These winds are the most unfavourable to the work of reclamation, especially during times of drought, for not only do they retard progress by scattering even specially thick layers of refuse, but they continually cause breaks in the recently reclaimed areas, and are extremely trying to the young plants. Apart from the movement of the dunes, quantities of sand are lifted by the gales from the summits of the ridges, and are swept on until some obstruction is encountered, when a new bank is rapidly formed. The District Forest Officer, in his Report for 1899, which was a very dry year, states:—"The whole sand-drift appeared, even during a moderate breeze, to be completely enveloped in a yellowish cloud which extended for miles out to sea." Such a condition, however, only occurs when both the wind and sands are dry, and it is then that the greatest movement takes place. The gales from the south and south-east are generally heavily charged with moisture, and often to such an extent that pavements look as if they had been sprinkled. The Author has seen water dripping from a galvanized-iron roof at about 5.30 p.m., which was entirely due to the condensation of moisture in the atmosphere. During such winds there is no movement of the sands. Dust and sand are not blown about to any appreciable extent by damp winds. After what has been stated with regard to the south-east gales at Port Elizabeth, the statement that the travel of the sands on the Cape Flats is due to the same winds will seem contradictory, but the local conditions are entirely different. Along the south-east coast of South Africa runs a hot-water current from the Indian Ocean known as the Mozambique Current. Further on its course, as it approaches Cape Agulhas, it is called the Agulhas Current. Warm air absorbs more moisture than does cold air, and the effect of the warm current on the climatic conditions is very marked, giving rise to a highly saturated atmosphere. At about longitude 20° E. it meets the cold Antarctic Current, which flows in a north-westerly direction, and deflects the Agulhas Current, causing it to double back on its course, thus extending its influence still farther to the south-east. The action of the Antarctic Current is to reduce the atmospheric temperature and lessen its capacity for retaining moisture, so that the south-east winds reach the Cape Peninsula as cool dry winds. Some idea of the temperature of this current may be gathered from the fact that icebergs are sometimes carried

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comparatively close to the African coast. In 1828, icebergs 100 feet in height were reported in latitude 35° 48′ S., and longitude 18° 5′ E.; in 1853 they were seen in latitude 36° S. and longitude 20° E., or 70 miles south of Cape Agulhas, while in January, 1850, small icebergs were seen 35 miles south of the Cape of Good Hope.

Mr. Bagneris, Inspecteur de Forêts, states[1] that the sand dunes at Gironde, in France, are sometimes 230 feet in height, but at Port Elizabeth the greatest height of any sand ridge yet fixed is 46 feet 6 inches, while many of them do not exceed 20 feet in height; and although their appearance is arid and desolate in the extreme, they are by no means devoid of moisture. In ordinary weather the sand is moist even 1 inch or 2 inches below the summits of the ridges, and water is found anywhere a few feet below the limestone crust—in some places at 1 foot from the surface. Numerous wells, 4 feet to 12 feet in depth, have been sunk for supplying the men and animals on the work. Laurent[2] mentions that the dunes in Algeria are so abundantly supplied that wells sunk to a depth of 10 feet or 12 feet contain water. Water is also found in the sands of Namaqualand. Its presence in the sand is generally attributed to capillary attraction. Marsh[3] also states: "It is observed that, from capillary attraction, evaporation from lower strata, and retention of rain-water, they are always moist a little below the surface." Andresen,[4] however, questions this, as he found that a heap of drift-sand was not moistened to a greater height than 8½ inches, after standing a whole night in water. But his experimental dune was probably far less compact than one in the natural state, and consequently the capillary attraction would be less marked. The loose layer of surface-sand prevents evaporation in the same way as the "tilth" or top-dressing which is used for retaining the moisture in the soil of cultivated land.

Rate of Movement of Sands.—Some experiments on six sand dunes at Eerste River show how erratic is the movement of various parts of a drift. Posts 10 feet in length were planted at ninety-one stations at the toe of the slope. In 8 months one station had advanced 300 feet, while at forty stations the movement had been less than 50 feet. By the end of 20 months five stations had receded and two had advanced between 500 feet and 570 feet.

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[1] Bagneris, "Manuel de Sylviculture."
[2] Laurent, "Mémoire sur le Sahara."
[3] See J. C. Brown, "Pine Plantations on the Sand-Wastes of France."
[4] Andresen, "Om Klit Formationen."

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The following is the official return :—

	May, 1889, to January, 1890. 8 months.	May, 1889, to January, 1891. 20 months.
Number of stations which had receded	..	5
Do. do. remained stationary	5	5
Do. do. advanced less than 50 feet	35	12
Do. do. between 50 feet and 100 feet.	26	3
Do. do. 100 feet and 200 feet	17	25
Do. do. 200 feet and 300 feet	8	8
Do. do. 300 feet and 400 feet	..	8
Do. do. 400 feet and 500 feet	..	2
Do. do. 500 feet and 570 feet	..	2
Number of poles which had disappeared (buried or stolen)	..	21
	91	91

Unfortunately this record is so incomplete that the movement cannot be plotted; the distance between the poles is not given, and there is nothing to indicate which of the ninety-one stations receded, or what was the position of the twenty-one missing poles after the first 8 months. It was estimated by one of the Forest officers that at Blue Down Sands, near Eerste River, the mean advance during 8 years had been at the rate of about 80 feet per annum. Mr. Hawgood, writing some 25 years ago, stated that observations on the Cape Flats showed an annual travel of 60 feet. Dr. Schlich [1] gives the movement of the sands in the Departments des Landes et de la Gironde as 60 feet to 70 feet a year, while Mr. Bagneris puts it at 15 feet a year. At Port Elizabeth, notes of two dunes taken in 1898 and 1899 indicate an advance of 50 feet per annum; but the differences were very great, and the period under observation far too short for reliable results. Another dune lately measured had in 2 years moved forward 30 feet at one flank and at the centre, while the other flank, which was in a sheltered position, had advanced only 15 feet.

Refuse.—The quantity of refuse required per acre varies within somewhat wide limits, depending as it does on the weather, the ground, and the character of the rubbish collected. The trucks for conveying the sweepings to the Port Elizabeth sands are of

[1] Schlich, "Manual of Forestry," vol. iv.

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about 310 cubic feet capacity. The contents were weighed in a few instances as a test, and were found to weigh 4 tons to 4½ tons per truck, but no attempt has been made to keep an account of anything except the number of the trucks. A large percentage of the stuff brought out consists of scrap tin, old buckets, pots, kettles, hoop iron, old iron bedsteads, wire, bottles, and empty tins of all sorts, and is quite useless for reclamation. The tins, however, are collected for use in the nursery.

The following extracts from the Report of the Forest officers will indicate approximately the amounts actually used :—

——	Year.	Tons of Refuse.	Actual Surface of Sand Spread, in Acres.	Tons per Acre.
At Durban River, Cape Flats	1877	4,000	80	50
„ „ „ „	1883	3,039	50	60
At Eerste River	1891	2,023	50	40
„ „ „	1892	5,247	150	35
„ „ „	1893	..	..	35
„ „ „	1894	..	..	40
„ „ „	1895	..	..	43
„ „ „	1896	..	..	59
„ „ „	1898	7,101	177	40

At Port Elizabeth the number of truck-loads of refuse used, and the total areas reclaimed, were :—

—	Number of Truck-loads.	Total Area reclaimed, in Acres.
Between 1893 and 1896	9,816	2,000
In 1897	3,121	500
„ 1898	3,452	480
„ 1899	3,740	425
	20,129	3,405

Taking a truck-load as 4¼ tons, this gives an average of slightly over 25 tons per acre, but in this case it represents the total area reclaimed, including sand, rocks, etc. Sometimes fifteen truck-loads, or 64 tons per acre of actual sand covered, are required. Rough broken surfaces require more refuse than smooth ground. It would appear that 45 tons per acre of sand fairly represents the average amount required to be actually spread.

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Plants and Trees used for Reclamation.—Numerous varieties of trees have been experimented with, but so far the *Acacia saligna* and *A. cyclopis* have proved the most useful revenue-producing plants. The bark of the former is a marketable commodity, containing a good percentage of tannin, but the bark is said to impart an unpleasant smell to the leather. The *Cyclopis* bark is of no commercial value, but the timber of both trees is used for firewood, for which there is a large demand in all South African towns, for domestic use. Many other Acacias have been tried, some of them far richer in tannin than the *Saligna*, but the results have been disappointing. Among these are the *Acacia pycnantha*, *A. decurrens* and its variety *A. mollissima*. The *A. pycnantha* produces excellent trees in several of the forest-plantations on the lower mountain-slopes, but on sand its growth is uncertain. It does not thrive at Port Elizabeth, and on large areas of the Cape Flats sands its failure has been almost complete. The same may be said of the *Mollissima*, which does well in more congenial soil, and is very largely cultivated in Natal, where it grows to an enormous size, even attaining a height of 60 feet in 10 years. At Fort Cunningham plantation, in Cape Colony, it outgrows and kills blue gums and pines, but these are not drift-sand growths. The *Acacia pycnantha*, *A. mollissima* and *A. melanoxylon* are subject to attacks of the Australian bug (*Iceria purchasi*). Some years ago they were almost exterminated by that pest, and the Agricultural Department imported and bred ladybirds (*Vedalia cardinalis*), which wage a most successful war against them. The Acacias (locally known as wattles, or Australian willows) mature in 8 years to 12 years, and are then fit for cutting. They shoot up again as coppice more rapidly than before, and on the South African drift-sands they grow more readily than any other tree. Although they seed profusely, there is but little germination until the cuticle has been scorched by fire. The seeds are very hard, and those sown broadcast during reclamation are soaked or boiled for hours until they are soft enough to be scratched by the finger-nail. Good germination takes place after 3 hours' boiling. Birds, especially the spreeuws (or starlings), attracted by the scarlet aril of the *Acacia cyclopis*, feed on the seeds, which, though not digested, are subjected to a softening process, and thus the tree is disseminated by nature. Hakeas and Fabricias also grow more densely after a fire. The return of dry *Saligna*-bark grown in drift-sands may be taken at about 2½ tons per acre. The cost of marketing is about £2 10*s.* per ton, which is more than covered by the sale of firewood. The greater the growth the more

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easily the trees can be stripped, and anything that induces long lanky growth is to be avoided. The growth from coppice gives a rotation of about 10 years. Some samples of *Saligna* have yielded 23 per cent. of tannin, but this percentage does not seem to be maintained. Three analyses made for the Agricultural Department, in 1894, gave the following results:—

——	A. saligna.	A. pycnantha.	A. cyclopis.
Percentage of tannin	22·45	18·65	6·5
" "	19·60	18·55	
" "	19·12	18·25	
and in 1899 another analysis gave—			
Percentage of tannin	22·92	26·04	

A large user of tanning bark in the North of England reported that the Port Jackson wattle has the advantage of producing a softer leather than the *Acacia mollissima*, and that Cape bark is lighter in colour than the Australian bark, which produces a deep-red-coloured liquor. The bark belongs to the pyrogallic class. Repeated efforts have been made to introduce the cluster-pine (*Pinus pinaster*) which is so successfully used on the French dunes, but so far without success. They failed on the sands at Eerste River and Durban Road, and fruitless attempts have been made at Port Elizabeth. This is probably due to the presence of lime, of which the cluster-pine is intolerant. Unfortunately no analyses have been made of the Port Elizabeth sands, but six samples from the Eerste River gave an average of 16·09 per cent. of oxide of lime. These analyses are given in the Appendix. According to Mr. Wessely,[1] the superficial sands in Gascony contain neither clay nor lime. The cluster-pine, however, when in suitable soil, grows luxuriantly in the Colony, and will spread itself by wind-blown seeds over large areas and up the rocky faces of mountains. A fine forest of these trees exists at Genadendal, where "trees as straight as a mast, and 70 feet to the first branch, are not uncommon." A log 102 feet in length has been cut in this forest; but this tree will not grow on all sand-wastes in France, and a somewhat similar case is that of the *Acacia saligna*, which thrives on most South African sands, but for some reason is not a success near the Gulchways at Port Elizabeth, although it is quite satisfactory a few miles off. It has been suggested that it will not

[1] Wessely, "Der Europäische Flug-sand und seine Kultur."

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stand the exposure to the south-west gales. Experiments are being made with the *Eucalyptus gomphocephala*, *E. diversicolor*, and *E. tereticomis* (a coast variety of *E. rostrata*), which are thriving on the Port Elizabeth sands. If the *E. diversicolor* succeeds, it should be a good source of revenue, as it yields the well-known karri timber. Some young plants, about a year old and 2 feet 6 inches in height when planted out, attained a height of 8 feet with a girth of 4 inches at 1 foot above the ground within a year. Several varieties of *Casuarinas* have been tried and found useless. An attempt, however, is to be made with the *C. equisetifolia*, which grows along the sea-coast in Mauritius and Madras. The *Hakea*, *Fabricia*, and *Callitris* are all good sand-plants, but unfortunately yield no revenue. The *Fabricia* (*Leptospernum laevigatum*) propagates readily, and is most effective in arresting sands in warm climates. Other useful trees are the *Tamarix gallica*, *Widdringtonia cupressoides*, and the *Cupressus macrocarpa*. There are many indigenous plants in the Colony, some of them of a very watery, succulent nature, which grow freely on the drift-sands, and under favourable conditions carry on a natural process of reclamation; but they, too, have no commercial value. Among these are the Hottentot Fig (*Mesembryanthemum edule*), *Mundtia spinosa*, *Chymococca empetroides* (sea-heath), the wax berry (*Myrica cordifolia* and *quercifolia*), *Colpoon compressum* (or Cape sumach), etc. The *Tetragona expansa*, or New Zealand spinach, grows luxuriantly on nearly pure sand, but is not indigenous. Other plants, such as the *Protea*, tobacco plant, bloembosch, wild cotton, and aloes, will grow in sand, but they can scarcely be regarded as suitable for reclamation. Of the grasses used in the Cape Colony, by far the most successful is the *Ehrharta gigantea* or pypgrass, the vigour of its growth far exceeding that of any other. Perhaps the most useful is the indigenous *Triticum junceum*, which is being used on the exposed littoral dune at Port Elizabeth, as it thrives well near the sea. The *Elymus arenarius* does not grow freely on the driest parts of the sands, and has, on the whole, shown poor germination, although in some cases healthy and strong. Extensive experiments have been made with marram grass (*Psamma arenaria*, also known as *Ammophila arundinacea* and *Arundo arenaria*), but the results have been very disappointing. At Eerste River the seeds only germinated at the foot of the hills experimented on, and the South African conditions appear to be unfavourable to its growth. In the nursery on the Port Elizabeth sands it grows well, but for broadcast sowing it is found less hardy than pypgrass and the *Triticum junceum*. In fact, the two latter have proved infinitely

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superior as sand-stays. At Port Fairy, in Victoria, drift-sands are converted into pastoral country by means of marram grass alone, and 100 acres are reported capable of carrying one hundred head of cattle for 6 months in the year, and in many other parts of the world it is most successfully used. Other useful grasses are the *Cynodon dactylon* and *Sporobolus matrella*, which were self-introduced at Eerste River and grew vigorously. The *Panicum* and *Stenotaphrum* are also indigenous grasses that do well on sandy soils. *Lygeum spartum* (cord grass) has not yet been tried, and experiments might be made with *Stipa tenacissima* (esparto grass), which is largely used on calcareous drift-sands in Algeria and Egypt. An acre is said to yield 6 tons to 10 tons of dry esparto grass, thousands of tons of which are imported into England annually for paper- and rope-making. The whole experience of drift-sands reclamation demonstrates that the system of culture at each locality must be determined by a special study of the conditions of the case.

Cost of Reclamation.—The cost of reclamation, which includes extension of railway-lines, sidings, shifting the portable track, raising and maintaining artificial barriers, mules, stables, etc., varies considerably. The average of 5 years' work at Eerste River was £10 1*s.* per acre, the cost ranging between £8 6*s.* per acre in 1892, and £16 9*s.* 11*d.* in 1896. In one case the actual cost of spreading 177 acres was £4 14*s.* 7*d.* per acre. At Port Elizabeth the cost of spreading and transport to the sands amounts to £5 per acre, and the expenses in connection with the mules for hauling the small trucks to an additional £2 per acre, making a total of £7 per acre. The present distance from Port Elizabeth is about 5 miles, and the charge for haulage is 4*s.* 1½*d.* per truck holding about 4¼ tons. Convict labour costs 1*s.* 6*d.* per day, and free labour 2*s.* 6*d.* per day. Thirty men are required to spread the refuse over one acre of sand. Dr. Schlich [1] estimates the average cost of fixing sands with grass at £15 per acre, with labour at 3*s.* per day. With convict labour at 1*s.* per day and bush plentiful, the cost is about £4 per acre for bush-reclamation at Port Elizabeth. The cost of the Harbour Board work at the Gulchways, including the coast-barrier, buildings, plant, and 7,140 yards of wire-fencing, was about £34 per acre. Their foreman estimated the cost of ordinary bush-reclamation at £21 per acre. One of the cheapest pieces of work done was that at the Strandfontein sands, near Cape Town, where, in 1899, 25 acres were planted with pypgrass, and 40 acres with marram at a cost of

[1] Schlich, "Manual of Forestry," vol. iv.

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£3 1*s.* 3*d.* per acre. The Paape Biesje Fontein reclamation, previously mentioned, which cost £55 per acre, is an example of what casual unsystematic work may cost.

In at least two parts of the world exists the curious phenomenon of sonorous sands. On the sands of Peru a musical sound like distant drums is frequently heard, and is attributed to the eddying of the grains of sand on the crests of the dunes. At Bondi, near Sydney, N.S.W., freshly-blown sands emit a musical sound when trodden on. Enormous areas of drift-sands exist in various parts of the world. They extend for leagues along the French coast, and are said to cover some 250 square miles in Denmark; Captain Sturt found dunes 200 feet in height in the vast wastes of sand in the interior of Australia; sand deserts exist in Arabia and the Transcaspian regions, while the Sahara, according to Mr. Pomel,[1] is covered with sand-dunes for one-ninth or one-tenth of its total area. They occur also to the south-east of Lake Michigan, in Peru, and at Port Nolloth, on the south-west coast of Africa. Tracts of blown sand are also found at various parts of the Scottish and Irish coasts. Wherever they spread they carry havoc and destruction in their paths, and with the extension of human enterprise the subject of reclamation will be one of increasing value and importance. Thanks to Brémontier, who in 1787 inaugurated the system that has been successfully continued to the present day, the French sands, instead of ingulfing farms and villages, have been converted into valuable pine-forests. In South Africa the results are in their way no less important. Durban Road, which years ago was a driving wilderness of sand, is now being laid out in building-lots. At Klipfontein, in the heart of the Cape Flats, a forest of acacias turned the course of an enormous drift and saved the whole village from destruction. At Port Elizabeth a residential suburb is being developed right in the teeth of the drift-sands, and the Harbour Board is constructing a large slip on the site of a farm that was buried 25 years ago.

The Paper is accompanied by a tracing, from which the Figure in the text has been prepared; and by the following Appendix.

[1] Pomel, "Le Sahara."

[Appendix.

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APPENDIX.

Analysis of Soil at Eerste River.

—	1 Surface Drift-sand.	2 Drift-sand 3 Feet below Surface.	3 Surface Soil after Drift-sand has passed over.	4 Soil 1 Foot below Surface when Drift-sand has passed over.	5 New Deposit found during Summer of 1892.	6 Old Deposit.
Moisture . . .	0·38	0·40	0·36	0·58	0·44	1·28
Ammonia . . .	0·004	0·003	0·003	0·003	0·003	0·003
Chlorine . . .	0·11	0·002	0·016	0·007	0·006	0·14
Phosphoric oxide .	0·09	0·04	0·07	0·04	0·01	0·01
Calcic oxide . .	15·98	18·50	16·27	11·56	15·57	18·66
Magnesium oxide .	1·11	1·42	0·78	0·22	5·21	4·95
Oxide of iron . .	0·17	0·25	0·21	0·21	0·25	0·32
Potassic oxide . .	0·24	0·12	0·26	0·20	0·16	0·28
Sodic oxide . .	1·46	0·63	0·66	0·82	1·00	0·80
Sulphuric oxide .	0·21	0·21	0·13	0·11	0·21	0·21
Carbonic acid . .	13·87	15·16	13·14	7·25	14·90	18·31

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(*Paper No. 3329.*)

"An Optical Method of Determining the Deformations of a Rotating Fly-wheel."

By SAMUEL HENRY BARRACLOUGH, B.E., Assoc. M. Inst. C.E.

IN the following Paper is described an apparatus which the Author has devised for measuring the elastic deformations of the rim and arms of a fly-wheel, due to the centrifugal action produced by rotation. To illustrate the method, several tests of the deflection at various points on the rim of an experimental fly-wheel are described. These formed part of a series of tests conducted in the mechanical laboratory of the P. N. Russell School of Engineering, at the University of Sydney.

As the quantities to be measured are very minute, it is evident that the experiments must be carried out with great accuracy. Magnification of the deflections by optical means was therefore adopted, as being most likely to yield successful results. The method described was suggested by Professor Marten's well-known mirror apparatus, a special device being added for observing the deflections during the rotation of the wheel.

Description of Experimental Fly-wheel and Mounting.—The general design of the experimental wheel, and of the attached measuring apparatus, is shown in *Figs. 1.* The wheel is mounted on a vertical steel spindle, 1½ inch in diameter and slightly tapered at the top where it enters the boss of the wheel. The spindle is carried in a frame, which is bolted to the bed-plate on an independent concrete foundation, measuring 5 feet by 2 feet 3 inches by 5 feet in depth and weighing about 3½ tons. The spindle is supported at the bottom on an adjustable centre, and at the top passes through a bearing, consisting of a brass bush tapered on the outside and cut through by six vertical saw-grooves to within ⅛ inch of the bearing surface at five places and completely through at the sixth, the bush being provided with an adjusting nut at each end. This arrangement was found to provide an extremely satisfactory adjustment. The spindle carries, in addition to the

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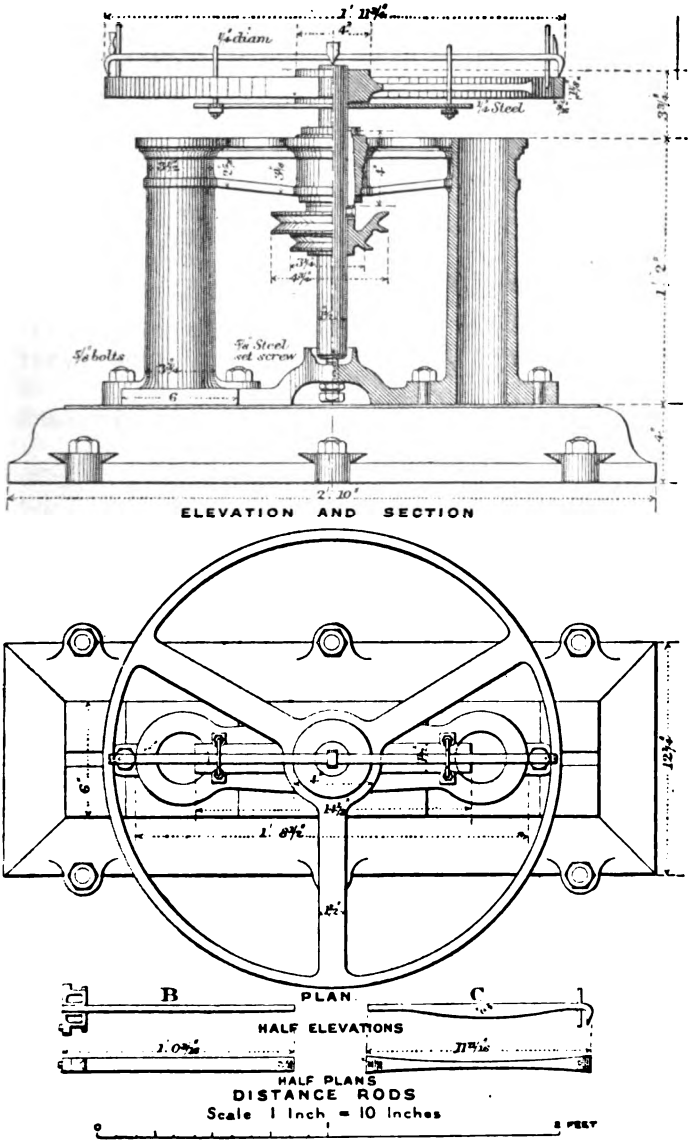
wheel, two pulleys, by means of which it is driven, and a bearing-

[*Figs. 1.*



EXPERIMENTAL FLY-WHEEL AND MOUNTING.

ring to prevent vertical motion of the spindle. Situated just under

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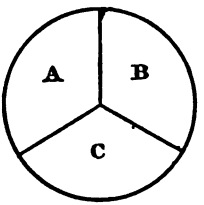
the wheel is a plate to carry the shackles, which originally were designed to apply pressure to the distance-rod of the measuring-apparatus and to keep it in place. This shackle-plate is attached to the boss of the wheel by small bolts which can be moved round in circular slots cut in the under side of the boss; in this way the shackle-plate can be placed in any desired position immediately under the distance-rod. The fly-wheel has three arms, which were made parallel to avoid a difficulty in computation pointed out by Professor Lanza, and the rim is rectangular in cross-section.

Fig. 2.



For convenience of reference, the wheel will be lettered as shown in *Fig. 2*, the arms being referred to as AB, BC, CA, and points on the rim as C15°, C30°, A60°, etc.

The following are approximately the dimensions of the different parts of the wheel:—

	Inches.
Outside diameter of wheel	23·7
Width of rim (radially)	0·55
Thickness of rim	1·15
Width of arms	1·5
Thickness of arms	0·42
Length of arms between rim and boss	9·32

The cross-section of the arms was approximately a rectangle with semi-circular ends. Special attention was paid to the balancing of the wheel and of all other parts which rotated on the spindle (e.g., distance-rod, pulleys, keys, bearing-ring, shackle-plate, and shackles). The pulleys and collar were turned on the spindle, and care was taken in the preparation of the surface of the top of the spindle, which acts as a bearing-plate for the prism of the measuring-apparatus. The running of the wheel, at least up to the maximum speed used in the series of tests described, was considered to be on the whole extremely satisfactory.

Physical properties of Material in Wheel.—An accurate series of tests was made of the cast-iron used in the wheel, and the following are the average values obtained:—

Density	446·8 lbs. per cubic foot.
Tensile strength	26,360 lbs. per sq. inch.
Modulus of elasticity	13,300,000 „ „
Modulus of rupture	36,960 „ „

Description of Measuring Apparatus.—The general arrangement of apparatus for measuring the outward deflection of the

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centre-line of the rim of the wheel is illustrated in *Figs. 1* and *Fig. 3*. It consists essentially of a steel distance-rod, one end of which is attached to the rim at the point whose lateral motion it is desired to measure, the other end being free, but touching the corresponding point in the rim at the opposite end of the diameter, while at the centre of the rod an accurate groove is cut, which bears upon a lozenge-shaped steel prism carried on the top of the spindle. The fixed end of the distance-rod, as it moves horizontally, accompanying the centre-line of the rim, causes the prism to rotate through an angle whose magnitude is determined by the lateral movement of the rim. Attached to the prism is a plane mirror which rotates with the prism and by means of which the angular motion of the latter is measured.

The general design of the distance-rod is shown at C, *Figs. 1*. The fixed end of the rod is held rigidly attached to the rim by two projecting "teeth," having sharp chisel-shaped ends. Minute chisel-grooves are cut in the rim to receive the tips of the teeth, and it was found that a very small pressure was sufficient to make the teeth adhere rigidly to the rim. The distance between the teeth is 0·57 inch, and the rod was placed in such a position that these were at equal distances on either side of the point whose lateral deflection was to be measured. The total weight of the rod is about 1 lb. 4 ozs. It was designed with a fairly deep web in order to prevent any appreciable bending in a vertical plane, and was placed on the wheel so as to be, as accurately as possible, horizontal, since any defect in either of these matters was found to cause serious error, as might naturally be expected. To ensure the distance-rod being horizontal it was, of course, necessary mutually to adjust the length of the teeth, the depth of the groove in the middle of the distance-rod, and the height of the prism.

The prism is approximately $\frac{3}{4}$ inch in length and $\frac{5}{16}$ inch in height, and carries above it and rigidly attached to it a plane mirror $\frac{5}{8}$ inch square, inclined approximately at an angle of 45°. The distance-rod passes freely underneath the mirror. It was originally intended to apply the required vertical pressure for the distance-rod by means of the two shackles, which are provided with knife-edges at their upper ends, and are so fixed to the shackle-plate at their lower ends as to be capable of moving freely, through a small arc, in the vertical plane containing the distance-rod and the spindle. It was found after numerous trials, however, that ordinary rubber-bands between the distance-rod and the shackle-plate constituted the most satisfactory arrangement, and these were used in all the later experiments. The

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shackles were, however, usually kept on the shackle-plate in case the distance-rod should get adrift, and short cylindrical pins were fitted at each end of the distance-rod for the purpose of preventing it slipping in the direction of its length; but neither of these safeguards was found to be necessary. Three forms of distance-rod were tried, one being shown in *Figs. 1* mounted on the wheel, and controlled by the shackles, and the others at B and C, *Figs. 1*.

Fig. 3.

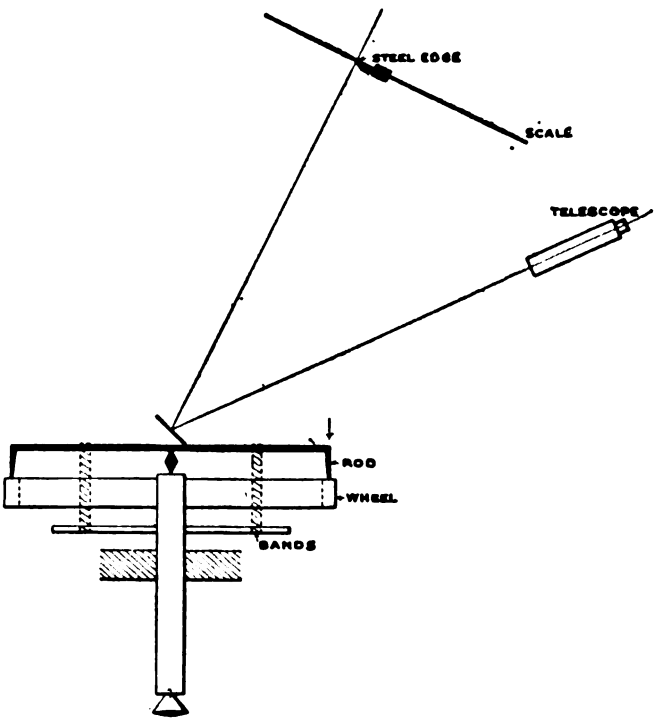

DIAGRAM OF ARRANGEMENT FOR MEASURING DEFLECTIONS.

The second one tried (B) was attached to the rim by means of a set-screw with a hardened point, but both this rod and the first one were found to have the serious defect of bending too readily in a vertical plane.

At a distance of about 3 feet 4 inches from the prism, and inclined at an angle of 30° approximately, is a fixed transparent glass scale, engine-divided into half-millimetres, *Fig. 3*. The

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standard to which the scale is attached has an independent foundation. Behind the scale is a broad yellow flame which illuminates the scale-divisions and makes them visible in the eye-piece of the telescope, which is of short focus, and can be moved either horizontally or vertically through small arcs by means of slow-motion screws. In order to measure the deflection while the wheel is rotating, the following scheme was devised. In the eye-piece of the telescope is fitted a micrometer divided into $\frac{1}{10}$ millimetres. The relative positions of the telescope-mirror and scale are so adjusted that the divisions on the scale appear to correspond precisely with the divisions of the micrometer. Hence deflections, if small, can be read either upon the large glass scale or upon the micrometer scale. Attached to the glass scale and capable of being clamped at any desired point on it, is a metal mounting consisting of two parts. One of these is always fixed in some definite position on the glass scale and serves as a kind of frame or mounting to which the second part is attached by means of a fine-threaded screw. This second part is really an accurately-made steel bevel-edge, capable of being moved up and down on the front of the scale through a small distance, by means of the screw. The bevel-edge is blackened in order to form a better image. The illuminating flame is placed directly behind this bevel-edge, which shows in the telescope field as a sharp black line across the middle of the field, the lower half of which is practically blotted out by the metal frame. In the upper part of the field there is always visible the micrometer scale already described. This sharp black edge is the datum-line from which the scale-deflections are measured, since, as the mirror deflects, the black edge appears to move either up or down in the field according to the direction of the mirror's rotation. The scale is, of course, visible only for a very small fraction of each revolution of the wheel; but even at low speeds it is possible to detect the point on the micrometer scale at which the black line passes, while at the higher speeds the flashes come so rapidly that the black edge shows continuously in the field, rising and falling with the changes in the speed of the wheel. This method of measurement would only be available for very small deflections were it not for the screw-thread attached to the steel bevel-edge and connecting it with the clamped frame. By means of this screw the bevel-edge can be moved either up or down on the glass scale so as to bring it approximately to the middle of the field again when the deflection has become such that it is either too high or too low, and the distance through which the bevel-edge has been moved by the screw can then be measured;

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in the experiments under description, however, it was not found necessary to use this attachment, as the deflections observed were all contained within the limits of the field. This form of apparatus was devised in the first instance in connection with an alternating-stress machine recently designed and built in the P. N. Russell School of Engineering.

If L denote the distance between the scale and the prism, and l denote the "height" of the prism (*i.e.* the distance between its knife-edges), and e denote the lateral extension of the rim, then very approximately—

$$e = \frac{l}{2L} \cdot R$$

where R is the scale reading. For the apparatus described this reduces to—

$$e = 0{\cdot}003768\ R$$

and, therefore, as one division on the glass scale is 0·5 millimetre, a deflection of one scale-division corresponds to a lateral extension e of 0·001884 millimetre. The deflections were read to $\frac{1}{10}$ of a scale division, by estimation, and this would correspond to roughly $\frac{1}{5000}$ millimetre. The estimation of $\frac{1}{10}$ of a scale-division could often be made quite accurately and with no difficulty, but at times an error of about $\frac{1}{10}$ to $\frac{3}{10}$ of a division was involved, the degree of accuracy varying with the clearness of the image and the steadiness of the wheel in running. This degree of precision applies only to the differential results, the order of accuracy of the absolute values being, of course, very much lower.

Correction for Extension of Distance-rod.—It is, of course, manifest that the deflection indicated by the telescope only determines the difference between the lateral deflection of the rim and the extension of the distance-rod, which is evidently subject to a varying tension due to its own centrifugal action, and to the centrifugal action of the small concentrated loads placed at its ends. The extension of the distance-rod would tend to rotate the prism in the opposite direction to that produced by the lateral extension of the rim, thus making the apparent movement of the rim less than it actually is. A correction for this can be easily applied, and is, under any circumstances, small in amount, although not negligible.

The distance-rods used were constructed of steel, the density and tensile properties of which were accurately determined. Samples of the same steel bar from which the rods were made were tested in tension, and their elastic deformations were determined

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by means of the Marten mirror apparatus. The following are the average values obtained :—

Coefficient of elasticity . . .	28,747,800 lbs. per square inch.
Breaking strength.	110,500 „ „ „ „
Density	484 lbs. per cubic foot.

It has been assumed, as sufficiently accurate for this correction, that the distance-rod is of a uniform section throughout, equal in area to that of the average cross-section, which is approximately 0·180 square inch. The extension of the rod at a speed of 1,000 revolutions per minute was found to be 0·000186 inch, or 2·5 scale-divisions, and it varies directly as the square of the speed.

Method of Driving and Speed of Wheel.—The wheel was originally arranged to be driven either by means of belts from a counter-shaft or by an electric motor, but at the time of these experiments the latter method was not practicable, so that the speed was limited to that obtainable by means of the shafting. The maximum speed employed was about 1,500 revolutions per minute, but in the great majority of the tests the speed did not exceed 1,200 revolutions per minute. It was found, however, that within these speeds the rate of rotation of the wheel could be very easily varied by allowing a certain amount of slip in some of the belts, and this was the method employed throughout. Practically all the observations were taken while the speed was being increased up to its maximum, only a few readings being taken on the return journey by way of a check. The speeds were measured by means of an electric chronograph, the vibrating stylus of which was controlled by a tuning-fork whose rate of vibration was 100 per second. The time of each revolution of the wheel was indicated by a second stylus actuated by a one-bar commutator attached to the lower end of the spindle and connected to a second battery circuit. In this way the speed at the particular instant of taking an observation could be determined, since the observer who was reading the deflections through the telescope made contact, by means of a small press-button, at the instant of reading, and, in addition, the acceleration or retardation of speed could be measured, if desired, by observing the time taken for successive revolutions. The controlling tuning-fork was tested against a seconds pendulum, and also by comparing it with a standard König fork, and its error was found to be inappreciable. The degree of precision obtained by this method of measuring the speed was of course very satisfactory.

Method of making a Test.—In the first place the distance-rod was placed on the wheel with the "toothed" end pressing into the fine

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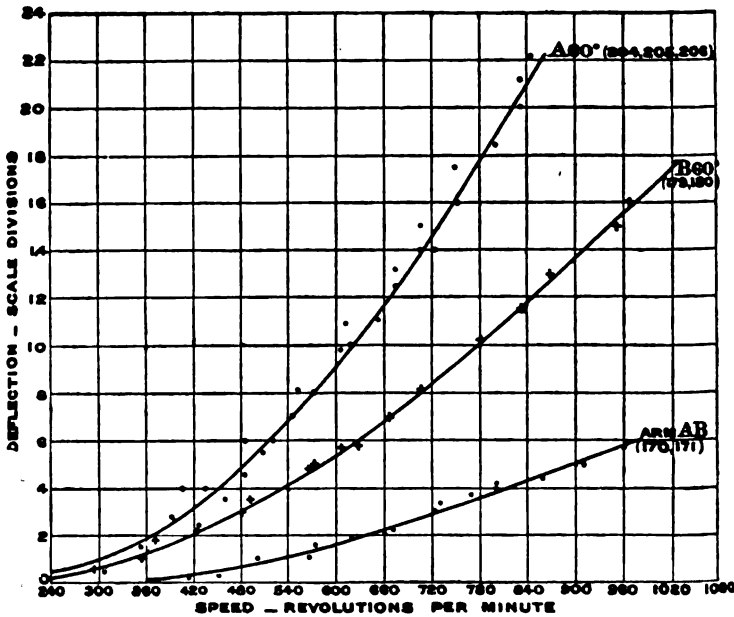
chisel-marks at the desired point on the rim. Two rubber-bands were then placed on each side of the distance-rod about mid-way between the spindle and the rim, and the rod was gently tapped once or twice with a light hammer above the teeth. The mirror was then adjusted so that the prism should be vertical. This could be done very readily merely by trial, the image of the scale being watched all the time through the telescope. No other adjustment of the mirror and prism was necessary, the mirror being rigidly attached to the prism once and for all. Some difficulty was at first experienced in preventing the distance-rod or the prism from

Fig. 4.



LATERAL DEFLECTION AT DIFFERENT POINTS OF THE RIM.

slipping through minute distances, and so altering the zero reading on the scale, but it was found that by speeding the wheel up once or twice before making the actual test the scale zero became practically fixed.

Two observers were required, one to read the deflection and the second to attend to the chronograph and to adjust the speed. The following was the procedure in making an observation:—The telescope observer gave a signal to the other to start the chronograph drum, then closed the circuit to the chronograph fork, and,

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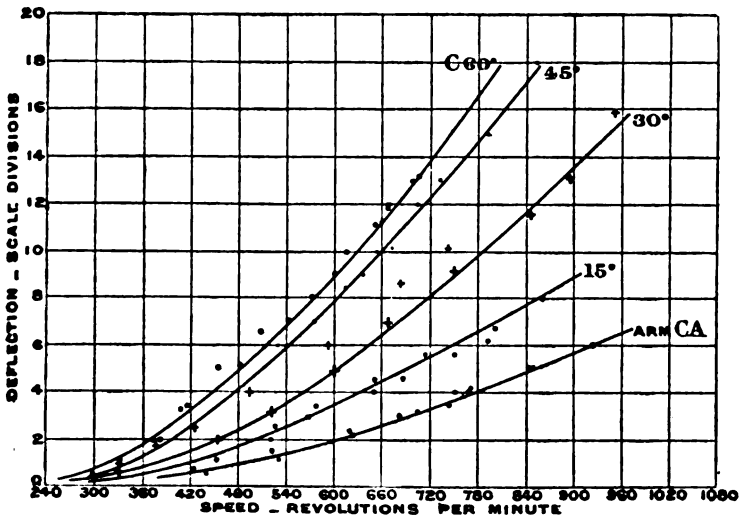
when ready, read the deflection on the scale and at the same moment pressed the key to close the commutator circuit, thus obtaining the time of each revolution just as the reading was being taken. This process was repeated at various speeds up to the maximum. It is perhaps worth noting that the slight friction between the free end of the distance-rod and the rim produced no appreciable effect on the scale-reading. This point was very carefully investigated, as it was at first thought that it might be necessary to put some form of roller-bearing between the free end of the distance-rod and the upper surface of the rim. This, however,

Fig. 5.



LATERAL DEFLECTION AT DIFFERENT POINTS OF THE RIM.

proved to be quite unnecessary. The acceleration of the wheel, unless very great, did not affect the deflection appreciably.

Lateral Deflection of Different Points of the Rim.—The results obtained from the various experiments are shown by curves in *Figs. 4* and *5*. In any particular test and in successive tests at the same point on the rim the observations, when plotted, are seen to lie on fairly smooth curves, approximately parabolic in shape. From these the curve of deflection of the centre-line of the rim can be obtained for various speeds, and a particular illustration of this is given in the form of a polar diagram in *Fig. 6*, which shows diagrammatically the deflection of the rim in the neighbourhood of the arm CA, for a speed of 750 revolutions per minute, the

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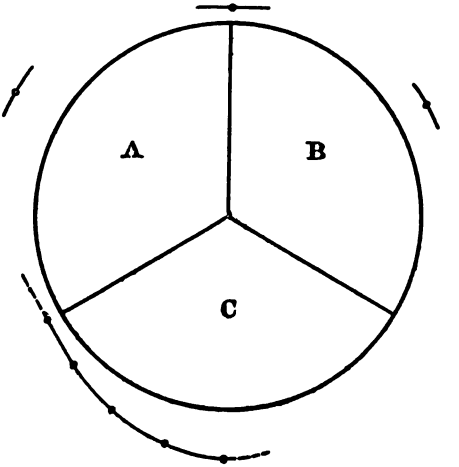
necessary correction being made for the extension of the distance-rod. It will be seen that there is a somewhat remarkable difference between the amount of lateral deflection of the centre-point of bays A or C and that of bay B, the latter being distinctly the smaller. This is apparently characteristic of the particular wheel, as a series of tests made with one of the other distance-pieces showed the same result. It is not easy to suggest the reason for this difference, unless it be caused by the (not very great) differences in the areas of the arms.

There is evidently a large field open for investigation in this subject, part of which it is hoped may be shortly taken up. Some of the matters which seem especially worthy of consideration are, the effect of curved arms, of joints in the rim, of differences in the number of arms, and the effect of acceleration and retardation. It is hoped also that experiments may be carried out on the expansion of rotating disks. The apparatus as here described is doubtless capable of very considerable modification and improvement. The design of the distance-rod especially is probably open to much alteration.

Fig. 6.



CURVE OF DEFLECTION OF CENTRE-LINE OF RIM.

In conclusion, the Author desires to express his indebtedness to Professor W. H. Warren, M. Inst. C.E., for his kindness in putting every facility at his disposal for carrying out this investigation, and for much help in the way of suggestion and advice; also to Mr. G. H. Knibbs, F.R.A.S., for great assistance in the way of counsel and advice, and to Mr. A. Boyd, B.Sc., who has been associated with him in practically all the experimental work of a long series of tests, of which a few are described in the foregoing.

The Paper is accompanied by two photographs and three chronograph records; and by twelve drawings, from a selection of which the Figures in the text have been prepared.

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(Paper No. 3332.)

"Formulas relating to Saturated Steam."

By ARTHUR WILLIAM BRIGHTMORE, D.Sc., M. Inst. C.E.

IN presenting the following investigation of formulas relating to saturated steam, the Author desires to emphasize the importance of considering the properties of steam from the point of view of its "intrinsic energy," *i.e.*, the amount of heat-energy contained in the steam at any particular temperature. One pound of saturated steam at any given temperature contains a definite quantity of heat-energy, its amount being altogether independent of the cycle of operations through which the steam has passed before arriving at the temperature in question. It will be observed that the "total heat of the steam" at a certain temperature is an entirely different quantity, for it comprises (1) the amount of heat necessary to raise water from 32° F. to the given temperature, (2) the amount of heat necessary to overcome the molecular resistances in converting the water into steam, and (3) the amount of heat which must be expended in making room for the steam at the pressure corresponding to the given temperature. The first two parts represent heat-energy existent in the steam, and together constitute its "intrinsic energy," whilst the third part is simply a concomitant of the production of the steam, and does not represent energy contained in the steam. In the cylinder of a steam-engine the intrinsic energy of the steam at the point of cut-off represents its power of doing work, while its intrinsic energy at the point of release represents the heat-energy rejected from the cylinder. The importance of the second part, as representing, under ordinary working conditions, inevitable loss of heat at the point of release, will be emphasized later.

Since 1 lb. of steam, at any given temperature, has a definite amount of intrinsic energy, it appears reasonable to suppose that a formula can be obtained expressing it in terms of the temperature. Having been led to consider the relative values of the intrinsic or internal energy of steam and that of water at the same temperature, the Author found that the ratio of the intrinsic

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energy of water (*i.e.*, the heat required to raise a given weight of water from 32° F. to the temperature $t°$ F.) to the difference between the intrinsic energy of the same weight of saturated steam at $t°$ F. and at 32° F. has a value whose rate of variation with the temperature is constant. If h be taken to represent the amount of heat, in British thermal units, required to raise 1 lb. of water from 32° F. to $t°$ F., and if ψ and ψ_o denote the intrinsic energy of steam, in British thermal units, at $t°$ F. and at 32° F. respectively, this property may be expressed—

$$\frac{d}{dt} \cdot \frac{h}{\psi - \psi_o} = \text{a constant} \quad . \quad . \quad . \quad . \quad (1)$$

Table I. (pp. 412–413), in which the figures necessary for the calculations are taken from Rankine's Tables for saturated steam, shows that, between the temperatures of 41° F. and 428° F., the ratio of h to $\psi - \psi_o$ varies between 5·27 and 4·56, the decrease of this ratio moreover being proportional to the increase of the temperature. In the Table Δ is the difference between consecutive lines in the 4th column.

Let H represent the amount of heat, in British thermal units, necessary to raise 1 lb. of water from 32° F. to $t°$ F. and evaporate it into steam at the latter temperature.

H_o the heat, in British thermal units, expended in evaporating 1 lb. of water at 32° F.

P_o and P the steam-pressures, in pounds per square foot, corresponding to the temperatures 32° F. and $t°$ F. respectively.

p_o and p the same pressures in pounds per square inch.

v_o and v the volumes, in cubic feet, of 1 lb. of saturated steam at the same temperatures.

T_o and T the absolute temperatures corresponding to 32° F. and $t°$ F.

s the volume, in cubic feet, of 1 lb. of water.

and J, "Joule's equivalent."

Then $\psi = H - \frac{P(v - s)}{J}$ and $\psi_o = H_o - \frac{P_o(v_o - s)}{J}$.

From the Table the constant in equation (1) can be readily determined, and the equation becomes—

$$\frac{d}{dt} \cdot \frac{h}{\psi - \psi_o} = -0{\cdot}00183 \quad . \quad . \quad . \quad . \quad (2)$$

Integrating this—

$$\frac{h}{\psi - \psi_o} = -0{\cdot}00183\, t + c,$$

where c is the constant of integration.

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From the Table it is easily seen that $c = 5{\cdot}34$, and from Rankine's Tables that $\psi_o = 1037{\cdot}92$.

The equation therefore becomes—

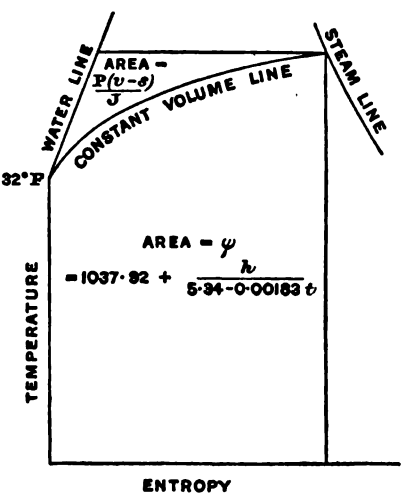
$$\psi = 1037{\cdot}92 + \frac{h}{5{\cdot}34 - 0{\cdot}00183\,t} \quad . \quad . \quad . \quad (3)$$

Or, representing $\dfrac{h}{5{\cdot}34 - 0{\cdot}00183\,t}$ by μ,

$$\psi = 1037{\cdot}92 + \mu \quad . \quad . \quad . \quad . \quad . \quad (4)$$

This expression is, of course, the area of the entropy diagram below the line of constant volume for any given temperature of saturated steam, *Fig. 1.*

Fig. 1.



It will be noticed that the accuracy of the figures in the fourth column of Table I. is not impaired by the fact that Rankine took "Joule's equivalent" as 772, instead of the now generally accepted value of 778, since each term in the ratio involves this quantity, $v - s$ being calculated from the formula—

$$(v - s)\frac{d\,\mathrm{P}}{d\,\mathrm{T}} = \frac{\mathrm{J\,L}}{\mathrm{T}},$$

L being the latent heat of evaporation, in British thermal units, for temperature T.

To show the degree of exactitude with which the expression approximates to the figures derived from experiment, the values of ψ in the third column of Table II. (p. 414) are taken from Professor Peabody's Tables for saturated steam,[1] those in the fourth column being calculated from equation (3).

The greatest difference between the figures given in the last two columns is 0·3, *i.e.*, less than 0·03 per cent., and the sign of the difference is sometimes positive and sometimes negative.

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[1] "Tables of the Properties of Saturated Steam and other Vapours," C. H. Peabody. J. Wiley and Sons, 1896.

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The formula (3) is thus seen to have a definite physica interpretation, and, moreover, it is of the same order of accuracy s the

TABLE I.

t	$\psi - \psi_0$	λ	$\frac{\lambda}{\psi - \psi_0}$	Δ
° F.	Foot-Lbs.	Foot-Lbs.		
32	6	0		
41	1,318	6,948	5·27	0·06 | 2
50	2,665	13,896	5·21	−1 | 2
59	3,992	20,844	5·22	0 | 1
68	5,317	27,792	5·22	3 | 2
77	6,695	34,740	5·19	0 | 1
86	8,034	41,702	5·19	2
95	9,405	48,650	5·17	1
104	10,782	55,612	5·16	2
113	12,173	62,560	5·14	2
122	13,595	69,522	5·12	3 | 2
131	15,028	76,484	5·09	1 | 2
140	16,433	83,459	5·08	2
149	17·850	90,435	5·06	1
158	19,279	97,411	5·05	2
167	20,747	104,387	5·03	2
176	22,207	111,363	5·01	1
185	23,667	118,353	5·00	2
194	25,186	125,357	4·98	2
203	26,645	132,360	4·96	1
212	28,155	139,363	4·95	2
221	29,678	146,380	4·93	2
230	31,213	153,412	4·91	

formula $H = 1082 + 0{\cdot}305\,t$; it may therefore be used in investigating the properties of steam in place of the empirical formulas,

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which, although they express a relationship between the variables, in most cases have no concrete meaning.

TABLE I.—*(continued)*.

t	$\psi - \psi_0$	h	$\frac{h}{\psi - \psi_0}$	Δ
° F.	Foot-Lbs.	Foot-Lbs.		
239	32,791	160,429	4·88	3 | 2
248	34,314	167,460	4·87	1 | 2
257	35,888	174,505	4·85	2
266	37,470	181,564	4·84	1
275	39,025	188,637	4·83	1
284	40,641	195,711	4·81	2
293	42,257	202,798	4·79	2
302	43,889	209,885	4·78	1
311	45,520	216,986	4·76	2
320	47,168	224,087	4·75	1
329	48,800	231,216	4·73	2
338	50,540	238,358	4·71	2
347	52,292	245,501	4·69	2
356	53,910	252,658	4·68	1
365	55,599	259,829	4·67	1
374	57,346	267,013	4·65	2
383	59,106	274,198	4·63	2
392	60,869	281,394	4·62	1
401	62,632	288,634	4·60	2
410	64,407	295,874	4·59	1
419	66,172	303,128	4·58	1
428	67,974	310,381	4·56	2

For example, this formula may be used in finding an expression for the specific volume of saturated steam in terms of the experimental quantities t, P and h :—

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From (3) $\frac{P(v-s)}{J} = H - 1037{\cdot}92 - \frac{h}{5{\cdot}34 - 0{\cdot}00183\,t}$,

substituting $H = 1082 + 0{\cdot}305\,t$,

$$v = s + \frac{J}{P}\left(44{\cdot}08 + 0{\cdot}305\,t - \frac{h}{5{\cdot}34 - 0{\cdot}00183\,t}\right)$$

or
$$v = s + \frac{J}{P}(44{\cdot}08 + 0{\cdot}305\,t - \mu) \quad . \quad . \quad . \quad (5)$$

an expression for v in terms of t, P and h.

TABLE II.

Absolute Pressure.	Temperature of Boiling Point.	ψ (British Thermal Units).	
		From Saturated Steam Tables.	Calculated from Equation (3).
Lbs. per Square Inch.	°F.		
1	102·0	1051·2	1051·5
14·7	212·0	1074·2	1074·4
25	240·0	1080·6	1080·6
50	280·8	1089·9	1089·8
75	307·4	1096·0	1095·9
100	327·6	1100·7	1100·8
125	344·1	1104·6	1104·8
150	358·3	1108·1	1108·4
175	370·6	1111·2	1111·5
200	381·7	1114·1	1114·3
225	391·8	1116·7	1116·9
250	401·0	1119·2	1119·3
275	409·5	1121·5	1121·5
300	417·4	1123·9	1123·6

Next, to find the rate of increase of the intrinsic energy of saturated steam with the temperature:—

Let this quantity be represented by C. By differentiating equation (3)—

$$C = \frac{d\psi}{dt} = \frac{d}{dt} \cdot \frac{h}{5{\cdot}34 - 0{\cdot}00183\,t}$$

$$\therefore\ C = \frac{(5{\cdot}34 - 0{\cdot}00183\,t)\frac{dh}{dt} + 0{\cdot}00183\,h}{(5{\cdot}34 - 0{\cdot}00183\,t)^2}$$

$$= \frac{1}{5{\cdot}34 - 0{\cdot}00183\,t}\left(\frac{dh}{dt} + \frac{0{\cdot}00183\,h}{5{\cdot}34 - 0{\cdot}00183\,t}\right).$$

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Or $$C = \frac{\mu}{h}\left(\frac{dh}{dt} + 0{\cdot}00183\,\mu\right) \quad . \quad . \quad . \quad . \quad (6)$$

But[1] $$h = t - 32° + 0{\cdot}000000103\,\{(t - 39°)^3 + 343°\}$$

$$\therefore \frac{dh}{dt} = 1 + 0{\cdot}000000309\,(t - 39°)^2.$$

Therefore when—

$p = 14{\cdot}7$ lbs. per square inch, $C = 0{\cdot}217$ B.Th.U.

and when $p = 300$ „ „ „ , $C = 0{\cdot}262$ „

It is easy to obtain from equation (3) an expression for the amount of heat necessary to overcome the molecular resistances in converting water into steam. If ρ denote this quantity in British thermal units—

$$\psi = \rho + h$$

or $$\rho = \psi - h.$$

Substituting for ψ—

$$\rho = 1037{\cdot}92 - (4{\cdot}34 - 0{\cdot}00183\,t)\,\mu$$

or $$\rho = 1037{\cdot}92 - \frac{4{\cdot}34 - 0{\cdot}00183\,t}{5{\cdot}34 - 0{\cdot}00183\,t} \times h \quad . \quad . \quad (7)$$

By taking the average value of the last term, and allowing for the slightly greater rate of increase of h compared with t, the expression may be written—

$$\rho = 1061{\cdot}3 - 0{\cdot}79\,t \text{ (approximately)} \quad . \quad . \quad (8)$$

which is the form of expression given by Zeuner.

To recognize the importance of this quantity ρ, it is only necessary to write down the expression for the work done by 1 lb. of steam expanding adiabatically in a steam cylinder. Let this be represented by U—

Then $$U = \frac{P_1\,(v_1 - s)}{J} + \psi_1 - \psi_2\,x - h_2\,(1 - x) - \frac{P_b\,v_2}{J}.$$

The suffix 1 refers to the point of cut-off, and the suffix 2 refers to the point of release.

P_b is the back pressure, and $1 - x$ is the proportion of the 1 lb. of steam that liquefies during adiabatic expansion.

The first term on the right-hand side of the equation is the work done during the conversion of 1 lb. of water into 1 lb. of

[1] "The Steam Engine," W. J. M. Rankine, 9th edition, p. 246.

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steam, the second term is the intrinsic energy of the steam at the point of cut-off, the third term is the intrinsic energy of the unliquefied portion of the steam at the point of release, the fourth term is the intrinsic energy of the liquefied portion at the same time, and the last term is the work done against back pressure.

It may be written—

$$U = H_1 - (\psi_2 - h_2)\, x - h_2 - \frac{P_3 v_2}{J}$$

$$= H_1 - \rho_2 x - h_2 - \frac{P_3 v_2}{J}.$$

Of the negative terms, h_2 represents heat which may be utilized to raise the feed-water to the temperature of the exhaust, P_3 may be reduced nearly to zero by condensing, but the remaining term $\rho_2 x$, where $x = \left(\log_e \frac{T_1}{T_2} + \frac{L_1}{T_1}\right) \times \frac{T_2}{L_2}$, which depends simply on the initial and final temperatures, represents inevitable loss as far as the engine is concerned, as it simply heats the condensation water, or is dissipated in the atmosphere in the case of a non-condensing engine.

Consequently ρ is seen to be important as representing unavoidable loss in the steam at the point of release; it can be reduced by expanding the steam as much as possible, but a definite loss occurs depending upon the temperature at "release."

Just as $$\psi = H - \frac{P(v - s)}{J}$$

so $$\rho = L - \frac{P(v - s)}{J}$$

And it is interesting to note that a relationship, of the form $\frac{d}{dt} \cdot \frac{\rho}{L}$ = a constant, exists.

It is easily found from the Tables that—

$$\frac{d}{dt} \cdot \frac{\rho}{L} = -\,0{\cdot}000146.$$

Integrating this and introducing the constant—

$$\rho = L\,(0{\cdot}956 - 0{\cdot}000146\, t) \quad . \quad . \quad . \quad . \quad (9)$$

In the following Table the values of ρ as calculated from formulas (7) and (9) are compared with the values given in Peabody's Steam Tables:—

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TABLE III.

p.	ρ from Equation (7).	ρ from Equation (9).	ρ from Peabody's Tables.
Lbs. per Square Inch.	B.Th.U.	B.Th.U.	B.Th.U.
14·7	893·7	893·5	893·5
50	839·6	839·4	839·7
100	802·9	802·8	802·8
150	778·4	778·3	778·1
200	759·7	759·7	759·5
250	744·6	744·5	744·5
300	731·7	731·9	732·0

This at once suggests a simple formula for L by combining equations (8) and (9), when the following equation is obtained:—

$$L = \frac{1061{\cdot}3 - 0{\cdot}79\,t}{0{\cdot}956 - 0{\cdot}000146\,t} \quad . \quad . \quad . \quad . \quad (10)$$

An equation for L involving only t to the first power.

The closeness of the agreement of the values calculated from this equation with the experiment values is shown in the following Table:—

TABLE IV.

p.	L from Equation (10).	L from Peabody's Tables.
Lbs. per Square Inch.	B.Th.U.	B.Th.U.
14·7	966·2	965·9
50	917·5	917·4
100	883·6	884·0
150	861·1	861·2
200	843·9	843·8
250	829·5	829·5
300	817·6	817·4

From equations (8) and (9) a formula for p in terms of t may be obtained, which is in a convenient form for calculation:—

$$\frac{P\,(v - s)}{J} = L - \rho$$

from (9)
$$= L\,(0{\cdot}000146\,t + 0{\cdot}044)$$
$$= \frac{(v - s)\,T}{J} \cdot \frac{d\,P}{d\,T}\,(0{\cdot}000146\,T - 0{\cdot}0233)$$

$$\therefore \frac{d\,P}{P} = \frac{d\,p}{p} = \frac{d\,T}{T\,(0{\cdot}000146\,T - 0{\cdot}0233)}.$$

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Integrating and finding the constant by substituting $p = 100$ lbs. per square inch, when $T = 788{\cdot}6°$:—

$$\log p - \log 100 = \frac{1}{0{\cdot}0233}\left(\log \frac{T - 159{\cdot}6}{T} - \log \frac{629}{788{\cdot}6}\right),$$

or
$$p = 100\left(\frac{788{\cdot}6}{629} \cdot \frac{T - 159{\cdot}6}{T}\right)^{42{\cdot}9}$$

or
$$\log p = 6{\cdot}21305 + 42{\cdot}9 \log \frac{T - 159{\cdot}6}{T} \quad . \quad (11)$$

In Table V. are given the values of p calculated from this formula for various values of t.

TABLE V.

t.	p from Formula (11).	p Experimental Value.
° F.	Lbs. per Square Inch.	Lbs. per Square Inch.
212·0	14·8	14·7
280·8	50·0	50
327·6	100·0	100
358·3	150·0	150
381·7	200·0	200
401·0	250·2	250
417·4	300·0	300

As a further proof of the accuracy of the foregoing formulas the following shows that h may be calculated from equations (8) and (9) to a high degree of accuracy; it is not suggested that the expression for h so obtained has any further value than affording additional evidence of the reliability of the formulas in question—

$$h + \rho = H - L + \rho$$
$$= H - (L - \rho),$$

substituting on the left from (8) and on the right from (9)

$$h + 1061{\cdot}3 - 0{\cdot}79\,t = H - L\,(0{\cdot}000146\,t + 0{\cdot}044)$$
$$= H - (H - h)\,(0{\cdot}000146\,t + 0{\cdot}044$$

substituting for H—

$$= (1082 + 0{\cdot}305\,t)\,(0{\cdot}956 - 0{\cdot}000146\,t) + h\,(0{\cdot}000146\,t + 0{\cdot}044$$
$$= 1034{\cdot}4 + 0{\cdot}134\,t - 0{\cdot}0000445\,t^2 + h\,(0{\cdot}000146\,t + 0{\cdot}044)$$

$$\therefore\ h = \frac{0{\cdot}924\,t - 0{\cdot}0000445\,t^2 - 26{\cdot}9}{0{\cdot}956 - 0{\cdot}000146\,t}$$

e.g. if $t = 240°$ F., $h = 208{\cdot}8$ (tabular value 209·1)
„ $t = 401°$ F., $h = 374{\cdot}9$ (tabular value 374·7).

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Having regard to the importance of the quantities ψ and ρ—the former as representing the heat-energy contained in 1 lb. of steam at any given temperature, and the latter as representing the inevitable loss of heat in a pound of steam at the point of release—the Author ventures to think that the formulas for these quantities—formulas (3), (7) and (9)—the accuracy of which is established by the foregoing applications, are of sufficient interest and importance to warrant their presentation to the Institution.

The Paper is accompanied by a tracing, from which the Figure in the text has been prepared.

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(*Paper No. 3341.*)

"On the Deformation of a Cast-Iron Pipe under External Vertical Pressure."

By JOSEPH FRANCIS, M. Inst. C.E.

BEING desirous of obtaining information with regard to the deformation of large cast-iron pipes under an external vertical pressure imposed by a weight of earth, and having failed to find any reliable records of observations or experiments on the subject, the Author decided to carry out an experiment which would be some guide to him in determining what thicknesses of metal were requisite for cast-iron pipes of 42 inches internal diameter, to enable them to carry, without undue deformation, depths of earth varying between 10 feet and 30 feet. The experiment described in the following Paper could not accurately represent the conditions of cases occurring in actual practice, but nevertheless it was believed that the results would afford indications and prescribe limits which would greatly aid in determining, in the interests of economy, the least thicknesses of metal required to ensure perfect safety.

The pipe experimented upon was made by the Staveley Coal and Iron Company. It was 42 inches in internal diameter, 12 feet in length, exclusive of the socket, which was hooped with steel and was 5 inches in length. The thickness of the barrel was 1¼ inch. The pipe was placed horizontally on cross-timbers laid close together on longitudinal planks resting upon a compact cinder floor. The socket projected beyond the timber and was unsupported. Saddle-blocks of oak, cut to the proper curve and 6 inches in thickness at the middle, were laid close together on the top of the pipe, reaching from the spigot end to the back of the socket moulding. At right angles to the axis of the pipe, long planks were laid side by side, resting at one end upon the saddle-blocks, and at the other end upon a vertical support placed at the same level as the tops of the saddle-blocks and at a distance of

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about 9 feet from the side of the pipe, *Figs. 1.* Upon that part of this flooring of plank immediately over the pipe, ten heavy weights were placed, one after the other, careful observations of the effect upon the pipe being made after the deposit of each weight. These weights were made up of pig-iron tied together by rails and bolts, each weight being between 5 tons and 6 tons. The total load ultimately placed upon the pipe was about $55\frac{3}{4}$ tons.

For measuring the extent of change of shape arising from the loads, four spring-gauges were used. Each of these was formed of a brass tube carrying a pointer, sliding inside an outer brass tube which had upon it a scale 3 inches in length, divided into sixteenths of an inch. The two tubes were kept extended to the limit of the scale by an internal spring. The inner tube had an internal

Figs. 1.

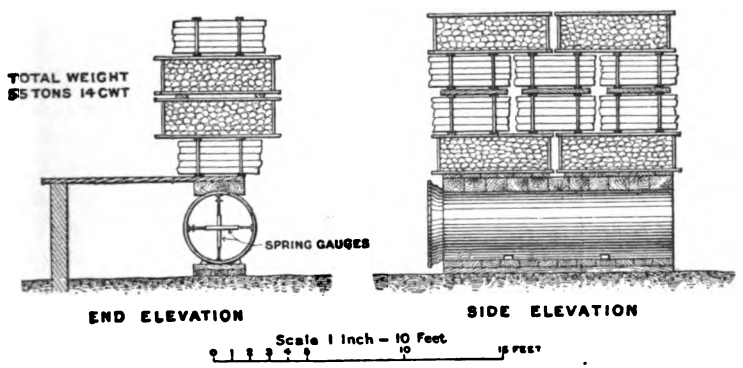

DIAGRAM SHOWING METHOD OF LOADING AND GAUGING.

thread, into which was screwed an iron rod terminating in a sharp centre, and the outer tube was provided with a small foot, fitting the curve of the inside of a 42-inch pipe, in order to prevent rotation of the gauge on its axis. The total length of the gauge was about 3 feet 8 inches, but by means of the screw on the rod the position of the pointer could be so adjusted as to bring it to the zero mark on the scale under any degree of compression of the spring. One of these gauges was inserted in the pipe in a truly vertical position at a distance of about 2 inches from the spigot end, and one gauge was similarly placed at an equal distance from the back of the socket. The centre-point was placed in a centre-punch mark at the top of the pipe, and the foot was set on the bottom. Gauges were also placed horizontally at either end of the pipe, passing through its axis, and close to the vertical gauges, a

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slight vertical support being put under the middle of each. The foot in this case abutted on one side of the pipe and the point rested in a centre-punch mark on the other side. Thus both the vertical deflection and the lateral extension of the pipe due to any weight placed upon it could be measured.

The form in which each of the weights was made up was such that two of them placed longitudinally reached from end to end of the pipe, and three placed transversely made up the same length. The ten weights were arranged in four tiers, viz., two weights longitudinally, then three weights transversely, and the same repeated, *Figs. 1.* Although the effect of each weight as it was added was carefully observed, it will probably be sufficient for all practical purposes to give the results obtained after each complete tier had been added. These are given in the following Tables:—

DIMINUTION OF VERTICAL DIAMETER OF PIPE.

Weight applied.		Diminution at Socket end.	Diminution at Spigot end.
Tons.	Cwts.	Inch.	Inch.
11	8	Very slight.	0·09
27	9	0·06	0·16
38	13	0·09	0·19
55	14	0·16	0·34

EXTENSION OF HORIZONTAL DIAMETER OF PIPE.

Weight applied.		Extension at Socket end.	Extension at Spigot end.
Tons.	Cwts.	Inch.	Inch.
11	8	Very slight.	0·09
27	9	0·06	0·16
38	13	0·09	0·19
55	14	0·14	0·34

The four aggregate weights given in the Tables represent roughly the weights of material deposited over a pipe if the trench in which it is placed is filled in with clay to the depths of about 5 feet, 12 feet, 17 feet, and 25 feet respectively. Although the conditions under which a pipe is subjected to pressure from earth placed above it could not be accurately represented in the

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experiment, it may safely be assumed that the distorting effects of the depths of earth mentioned would be less than that produced in the experiment by the corresponding weights of iron, inasmuch as the ground filled in on each side of a pipe in a trench exerts a pressure which tends to prevent the bulging of the sides of the pipe.

The following is an analysis of the iron of which the pipe experimented upon was made:—

	Per Cent.
Combined carbon	0·58
Graphitic carbon	2·80
Manganese	0·85
Silicon	1·60
Sulphur	0·07
Phosphorus	1·48
Iron (by difference)	92·62
	100·00

The tensile strength of the metal is about 10 tons per square inch, and a bar 1 inch in width and 2 inches in depth, resting upon knife-edges 3 feet apart, deflects in the middle to the extent of 0·385 inch before breaking, under a weight of 30 cwts. applied halfway between the supports.

The Author desires to thank Mr. F. Gandy, Works Manager to the Staveley Coal and Iron Company, for having put at his disposal, for the purposes of this experiment, the ample resources of these Works.

The Paper is accompanied by a photograph; and by a tracing, from which the Figure in the text has been prepared.

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OBITUARY.

FREDERICK ATTOCK died on the 21st May, 1902, at his residence, Garden Hill, Windermere. He was born at Liverpool on the 10th February, 1846, and served an apprenticeship under his father, Mr. George Attock, then Superintendent of the Carriage and Wagon Department of the Great Eastern Railway. He succeeded his father in that post in the year 1874, and in 1877 he was appointed Superintendent of the Carriage and Wagon Department of the Lancashire and Yorkshire Railway, which office he held until 1895, when he retired owing to ill health.

Mr. Attock was elected an Associate of the Institution on the 5th December, 1882, and transferred to Member on the 3rd February, 1891.

JAMES RANSON BAASS, born on the 25th January, 1861, received his preliminary scientific training at the Royal Polytechnic in Hanover. After serving a pupilage to the firm of Messrs. Wells Owen and Elwes, of Westminster, he acted for them as Resident Engineer on a section of the Hounslow and Metropolitan Railway for two years. From 1885 to 1887 he was engaged in the Drawing Office of the New South Wales Government Railways, and in making the survey and location for the extensive approaches and bridge across Sydney Harbour; and, in conjunction with another Office of the Service, he prepared sketch designs for the same under the direction of the late Sir John Fowler, Past-President, who was at that time on a professional visit to the Colonies. In 1887–88 he was employed in carrying out surveys and in superintending the preparation of working drawings, estimates and specifications for the Longwarry and Yanathan Railway in Victoria; and in municipal, hydraulic, railway, road and bridge work for Messrs. Hodgson and Smith, of Melbourne. In 1889 he carried out improvements on a section of the existing lines of the Victorian Government Railways, and from the same year, until 1891 he held the post of Engineer to the Shire of Yackandandah, an extensive and mountainous district in Victoria. After being engaged from 1892 to 1894 in the preparation of rail-

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way plans, and in the survey of roads and waterworks at San Pablo, California, he returned to England in 1895.

Towards the end of 1895, Mr. Baass was appointed a District Engineer on the Uganda Railway, having been one of the first engineers engaged for the construction of the line. He reached Mombasa in December, and was placed in charge of the first survey party, and, with the exception of about 40 miles, laid out the whole line as far as Nairobi, 325 miles. He was then appointed Superintending Engineer in charge of surveys for the last 200 miles over the Mau Escarpment to Lake Victoria Nyanza, and completed the final surveys in April, 1900, when he was appointed Superintending Engineer on the construction of the same section, and had charge of the advance divisions, consisting of earthworks and platelaying, the total force amounting to over 10,000 men. It was owing to Mr. Baass's untiring energy and hard work that the last 100 miles of the railway, by far the most difficult on the whole line, were laid in less than a year. His career was prematurely cut short by an accident, which took place on the 20th March, 1902. Travelling on a trolley in company with Mr. Waring, an Assistant Engineer, down the gradient beyond Lumba Station, he came suddenly upon an engine. There was no time to apply the brake effectively and a collision took place, Mr. Baass being so seriously injured that he died within three hours, while one of the trolley-men, who pluckily endeavoured to put on the brake, was killed on the spot. Mr. Waring, who jumped off, had a narrow escape. Mr. Baass was a capable engineer, and his zeal and ability were fully appreciated by those with whom he served. In respect of his work on the Uganda Railway, Sir Guilford Molesworth reported in 1899 as follows: "Of the survey and setting out I cannot speak too highly. Involving, as they have done, the examination and traversing of numerous alternative lines in a difficult country, they have resulted in a wonderfully easy line, considering the broken character of the ground."

He was elected an Associate Member of the Institution on the 2nd March, 1886, and was transferred to the class of Members on the 19th December, 1900.

GEORGE BUCHANAN, son of Mr. George Buchanan, Engineer, of Edinburgh, and nephew of Professor Faraday, was born in Edinburgh on the 8th December, 1834, and was educated at the High School and the University in that city. In 1851 he became

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a pupil of Mr. John Hawkins, Resident Engineer at Granton Harbour, with whom he remained until 1853, when he was taken into the office of Mr. James Walker, Past-President. There he was engaged until 1858, during which time he gained extensive experience in the design and execution of important works connected with harbours, docks, lighthouses and canals, among which may be mentioned the Government harbours of Dover and Alderney, the Bute Docks, Cardiff, and the Birmingham canals.

In 1859 Mr. Buchanan obtained an appointment from Mr. (afterwards Sir John) Fowler, Past-President, to go to Portugal on railway surveys, and on his return in 1860 he was appointed a Resident Engineer on the works of the Madras Irrigation and Canal Company. Returning from India in 1863, he was next sent to the Argentine Republic to survey and report on a line of railway.

From 1864 to 1868 Mr. Buchanan was engaged in England in the service of Messrs. Smith, Knight and Co., and of Messrs. William and John Pickering, contractors, and in 1869 he was instructed by the Secretary of State for India to survey and report on a proposed line of railway across the Western Ghauts. The work involved was of a most arduous description, and at one time the whole of his staff were laid up with fever, his chief assistant dying in the jungle. The survey, however, was completed to the entire satisfaction of Government, and Mr. Buchanan returned to England in 1870.

From 1871 to 1878 he remained in this country, being engaged as Resident Engineer on the Whitby and Lofthouse Railway, and as contractors' Engineer and Agent on the Port Talbot docks and breakwater, and on the graving dock in Devonport Dockyard.

From 1878 to 1887 Mr. Buchanan practised on his own account both in London and in South Africa, his principal work being the design and execution of the Kimberley Waterworks. In these works Mr. Buchanan introduced a novel feature by the use of 14-inch wrought-iron pipes for 17 miles of main, rising 500 feet, the principal reason for their adoption being the great cost of carriage up country.

In 1888 Mr. Buchanan went to Malta for a short time as Manager of the Railway, and in 1889 he was appointed by Messrs. Meiggs and Son their Agent on the works of the Chignecto Ship Railway in Nova Scotia. This work, the engineers for which were Sir John Fowler, Sir Benjamin Baker, Past-Presidents, and the late Mr. H. G. C. Ketchum, was designed to connect by means of a ship-railway the Gulf of St. Lawrence with the Bay of Fundy.

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Well planned and with every prospect of success, the finances of the company unfortunately failed when the railway and docks were on the eve of completion.

Mr. Buchanan returned to England in 1892, and after being engaged on various minor undertakings at home, he retired from active work in 1899. He was a man of untiring energy and unswerving honesty. Of a generous and amiable disposition, he made friends wherever he went. He married, in 1864, Emily, a daughter of Mr. Thomas Boosey, the music publisher, and the shock caused by her death at Kimberley, in 1882, was one from which he never entirely recovered. He died suddenly of heart failure at his residence in Chiswick on the 3rd May, 1902.

Mr. Buchanan was elected a Member of the Institution on the 24th May, 1870.

HENRY RICHARD CARLETON, fourth son of the Rev. Henry Carleton, Rector of Frankfort, near Dublin, was born in King's County, Ireland, on the 9th November, 1850, and was educated at Rossall School, Lancashire, and at Trinity College, Dublin, where he took the degrees of B.A. and M.A.I. After serving articles to Mr. James Dillon, under whom he gained experience in railway and drainage works in Ireland, he was employed for two years on exploration and location surveys on the Canadian Pacific Railway from Lake Superior to Winnipeg. The low temperatures to which he was subjected during the Canadian winters brought on inflammation of the lungs and compelled him to return to Ireland, and subsequently to spend some time in the South of France. Recovering from his illness he again served under Mr. Dillon, being employed on drainage works in Kildare and in other parts of Ireland.

In 1879 Mr. Carleton entered the service of the Harbours and Rivers Branch of the Public Works Department of New South Wales. He was first employed as a Surveyor on the Newcastle and Maitland water-supply scheme, and in 1882 was appointed Resident Engineer on the Lake Macquarie Harbour Works. Various schemes had been suggested for the improvement of the bars of the harbours on the New South Wales seaboard, and Mr. Carleton was entrusted with the marine surveying of the entrances. Whilst thus employed the opportunity was given him of forming ideas for the permanent improvement of the entrance channels to some of the rivers which the authorities subsequently decided to take in hand; and many years after, when

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the designs for the permanent improvement of these rivers were prepared, the knowledge Mr. Carleton then gained was most valuable to the Department. In 1889 he went to Orange as Resident Engineer during the construction of the waterworks for that town, which had been designed by the Department. In the beginning of 1890 he was removed to Sydney and given the appointment of Assistant Engineer at the head office of the Harbours and Rivers Branch, where he was engaged under Mr. C. W. Darley, then Engineer-in-Chief for Harbours and Rivers, in connection with the various schemes for harbour works for the northern rivers of the colony.

In 1895, on a reorganization of the Works Department, Mr. Carleton was appointed Principal Assistant Engineer for Harbours and Rivers under Mr. C. W. Darley, who had become Engineer-in-Chief for Public Works, and in that capacity he designed and carried out many important works for the improvement of the harbours of New South Wales.

In 1899 Mr. Carleton, whose health had never been robust, broke down whilst discharging his duties, and subsequently retired from the public service. He died on the 5th December, 1901, at his residence, Nelson Street, Woollahra, Sydney. He was an engineer of exceptional ability and had endeared himself to all who came in contact with him, both in his official and private capacity. Mr. Carleton was a Member of the Royal Society of New South Wales, and contributed to that body an important paper on "The Lighthouses of New South Wales."[1]

He was elected an Associate Member of the Institution on the 18th May, 1886, and was transferred to the class of Members on the 6th January, 1891.

BRYAN DONKIN[2] died suddenly of heart failure, at the Grand Hotel, Brussels, on the 4th March, 1902, in his sixty-seventh year. Born in London on the 29th August, 1835, he was the eldest son of a well known engineer, John Donkin, and the grandson of a still more brilliant engineer and scientist, Bryan Donkin, one of the first Vice-Presidents of the Institution, who founded the works in Bermondsey in 1803, and effected improvements in both printing and paper-making machinery with which his name will always

[1] Proceedings Royal Society of New South Wales, 1898.

[2] Portions of this notice are reprinted, by permission of the editors, from *Engineering*, 7th March, 1902.

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be associated. Bryan Donkin, Junior, as he was known for many years, was educated at private schools and at University College, London. On the completion of his studies in London he went to the École Centrale des Arts et Métiers in Paris, where he spent two years. Just after his twenty-first birthday, he entered the works in Bermondsey, then managed by his uncles, his father having died in April, 1854. He served his apprenticeship in the works till 1859, when he was sent to St. Petersburg to superintend the completion and erection of the then largest paper-mill in Europe, for the making of Imperial bank notes and state papers. In 1860 he paid a flying visit to England, arriving at the time of his grandfather's death. Permanently leaving St. Petersburg in January, 1862, he was employed for the next six years at the Bermondsey works, by his uncles, in designing and in superintending the erection of many important undertakings, several of which were on the Continent. There is no doubt that at this time he laid the foundation of an acquaintance with European engineers and machinery practice which served to influence his after career, for it is certain that his friendship with Professor Dwelshauvers-Dery, Hirn, and others, directed his energies into those paths of experimental research along which he subsequently worked, to the best advantage of the profession.

He became a partner of the Donkin firm in 1868, and when the business was converted, in 1889, into a limited liability company, he was appointed Chairman, and continued to hold that position after the amalgamation with Messrs. Clench and Co., of Chesterfield, in 1900. At this time, however, he relinquished active participation in the management of the works.

In the early seventies circumstances had so affected the paper-making industry that it had ceased to engage the works so fully as formerly; and thus the subject of this memoir had his attention directed to the scientific side of engine-design. About this time the firm introduced the Farey engine—Mr. Farey being a partner. In this design the cylinders were placed in line, back to back; the high-pressure cylinder was situated near to the crankshaft, while the low-pressure cylinder worked with its piston away from the crank. Both piston-rods had separate crossheads, which were connected by rods passing along each side the cylinder, and so arranged that the pistons were supported through the crosshead slides, which had ample bearing surfaces—an arrangement that prevented the pistons from dragging on the bottom of the cylinders and minimised wear. An engine so made for a paper-mill in Devonshire was very effectively tested with the view of arriving at its efficiency. Such trials are quite common to-day; but were

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then very exceptional, millowners accepting a rough approximation of economy, arrived at by a comparison with the conditions which formerly prevailed, irrespective of any standard upon which to base such deduction. The results of the trial, showing a consumption of 20·55 lbs. of water per horse-power hour and a coal-consumption of 1·9 lb., are set out in *Engineering* of the 3rd November, 1871.

This was the first of a long series of tests of engines and boilers undertaken to the end, for the last was made with a boiler at Fraser's Bow Works in February, 1902; the report was prepared, but never signed. It is difficult to fully appraise the wide influence of such successive trials, of the lessons they inculcated, and of Mr. Donkin's incessant advocacy of such scientific measurements as to the true possibilities of all prime movers. Even to-day there is too great readiness to accept results in mechanics generally which seem favourable, without fully determining their real merit or hunting for remediable defects in detail. As long ago as the 5th February, 1875, *Engineering* commended Mr. Donkin's work, while pointing out the simplicity of such steam consumption tests, measured as they were then by the weight of water flowing over a tumbling bay, on which subject he and the late Mr. Frank Salter contributed a Paper to the Institution.[1] Perhaps his first most effective examination was in connection with steam pumps for the Barnet Waterworks, where he made a complete balance-sheet to show the effective work done, as measured by the water pumped, and its proportion to the heat value of the fuel used.[2]

From this general work to investigations toward improvements in detail was but a natural step; and one department in which Mr. Donkin did specially valuable service had reference to steam condensation in cylinders, its reduction by jacketing and superheating, and to the investigation of the laws governing the transmission of heat through cylinder walls.[3] From the early seventies this subject had fascination for him, and in dealing with it he became directly associated with Professor Dwelshauvers-Dery; but it was not until about 1888 that he perfected his "revealer" a simple apparatus, frequently described, wherewith he was able to make diagrams illustrative of the extent of condensation under varying conditions.[4] By this apparatus definite knowledge of

[1] Minutes of Proceedings Inst. C.E., vol. lxxxiii. p. 377.
[2] *Ibid*, vol. lxvi. p. 278.
[3] *Ibid*, vol. xcviii. p. 250.
[4] See *Engineering*, vol. lxii. p. 788; also a paper read by Mr. Donkin before the Institution of Mechanical Engineers in October, 1900.

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state of the internal walls of cylinders was afforded; and the long series of trials made by himself, and in collaboration with others, including Dr. Kennedy, Professor Hudson Beare, and Lieut.-Colonel English, has borne direct practical fruit. It is scarcely necessary here to review at length his recent work in this direction. It established the advantage of the covers as well as the barrels being jacketed, and the value of superheated steam in reducing such initial condensation; but, on the other hand, he continued doubtful as to whether the very high degree of superheat in some modern apparatus brought a gain corresponding to the cost expended in the process and the practical troubles involved.

Early in the nineties Mr. Donkin directed his attention to internal-combustion motors, and found in them also a subject congenial to his inquiring disposition and facile pen. In 1894 he read a Paper before the Incorporated Institute of Gas Engineers, reviewing the comparative merits of steam and gas motors; and in the same year prepared for the Manchester Association of Engineers a review of the scientific work of Hirn, which is as lucid as it is instructive and sympathetic. A year later Messrs. Griffin published the first edition of his standard work on "The Gas Engine," now in its third edition, and later he translated Diesel's work on "The Theory and Construction of the Rational Heat Motor." At the same time he was himself engaged in original research-work in connection with internal combustion engines, and he acted as a judge for the Royal Agricultural Society, and at other competitions.

The steam boiler was always to him a source of inspiration, and together with Dr. Kennedy he made most exhaustive tests of twenty-one different types of boilers which were published some eight years ago in the columns of *Engineering* and were subsequently issued by that journal in book form. While establishing desiderata, they diagnose ills, and from this point of view stand as records for guidance in design, construction and working. He also published, through Messrs. Griffin, in 1898 a book on the steam boiler, with details as to the heat value of fuel, analyses of gases, evaporation, &c. He introduced at his works the Perret system of forced draught, the manufacture of which apparatus was taken up by his firm and successfully developed. In this system deep and thin bars are used, the lower portions of which are immersed in a trough of water, over which the forced draught is carried on its way between the bars, the aim being to keep the grate cool, so that dust and fine coal can be burned without any clinker adhering. On this subject he read a Paper in 1892 before the North of

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England Institute of Mining and Mechanical Engineers. In conjunction with Mr. J. Holliday, he also did some experimental testing with fuel calorimeters.[1] Centrifugal fans formed the subject of other investigations,[2] while about twelve years ago he worked upon the velocity of air through pipes with anemometers at the Vauxhall Water Works,[3] the results in all three cases being given in Papers to this Institution. In later years, too, motor-cars absorbed much of his attention as a member of the Automobile Club and as a manufacturer of the motor.

Space forbids fuller reference to these and other subjects which occupied Mr. Donkin's versatile and active mind. There are few volumes of the Proceedings of the leading technical Institutions without some contribution from him, for he was as willing as he was able from his extensive practice to add to the profit derivable from any discussion. Well informed, precise in his methods, clear in his deductions, his Papers were always appreciated, while his intervention in debate, even if it were only to ask for elucidation of some indefinite point was ever welcome. He was a Vice-President of the Institution of Mechanical Engineers, a Member of the Royal Institution, of the Société Industrielle de Mulhouse, of the Verein Deutscher Ingenieure, and of the American Society of Mechanical Engineers; and alike for his great ability and his geniality, he was widely beloved, and his loss will be deeply regretted.

Mr. Donkin was twice married, first, in 1869, to Georgina Dillon, daughter of Mr. Frank Dillon, and secondly in 1887 to Edith Marshman Dunn, née Edith Marshman, who survives him, and who in latter years rendered him valuable assistance in his literary work.

Mr. Donkin was elected a Member of the Institution on the 5th February, 1884. In addition to the Papers already referred to he contributed to the Proceedings: "A Method of taking the Temperature of the Cylinder Walls of a Steam-Engine at Different Depths in the Metal,"[4] "Thermometers in and about the Cylinder Walls of Steam-Engines, with some Experiments on the Temperature of the Metal under Different Conditions,"[5] "Experiments on the Condensation of Steam in Cylinders of Iron and other Metals,"[6] and "Motive Power from Blast-Furnace Gases."[7] For his Papers he was awarded by the Institution a Watt Medal,

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[1] Minutes of Proceedings Inst C.E., vol. cii. p. 292.
[2] *Ibid*, vol. cxxii. p. 265.
[3] *Ibid*, vol. cxi. p. 345.
[4] *Ibid*, vol. c. p. 347.
[5] *Ibid*, vol. cvi. p. 264.
[6] *Ibid*, vol. cxv. p. 263.
[7] *Ibid*, vol. cxlviii. p. 1.

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Telford Premium, and a Manby Premium. He also rendered valuable service as a Member of the Committees appointed by the Institution on the Thermal Efficiency of Steam-Engines and on Steam-Engine and Boiler Trials.

JOHN HOPKINSON was born in Manchester on the 11th February, 1824. During boyhood he showed a marked taste for handicraft and constructive pursuits, spending his spare hours and holidays watching and assisting the builders' workmen engaged near his home. The practical knowledge and skill thus early obtained stood him in good stead in later life. He was educated at private schools, and in 1840 was bound apprentice to Messrs. Wren and Bennett, millwrights and engineers, of Manchester. He soon obtained the confidence of his employers, and when only nineteen years of age was entrusted with the entire charge of the erection of the India Mills, Stockport, built to hold 70,000 spindles and 1,000 looms. He personally designed the buildings, set them out and supervised the making and erection of the ironwork and gearing. After the completion of his indentures he remained in the employment of the firm until 1848, when he became a partner. He remained a partner, the firm becoming later Wren and Hopkinson, until the end of 1881. He then retired to enter on consulting practice with his third son, Charles, who had been his assistant from 1873. The firm of Wren and Hopkinson and its predecessors had for many years acted as millwrights to Messrs. Chance Brothers, and in 1856 was consulted by the late Sir James Chance as to machinery for grinding and polishing the lenses required for his dioptric lights. Mr. Hopkinson designed a complete equipment of machinery for this purpose which attained the desired object with most satisfactory results. In 1868 he was consulted by the Lancashire and Yorkshire Railway Company as to better means of handling wagons and goods in their goods stations. He re-arranged some of the principal yards, notably at Howard Street, Liverpool, Oldham Road and New Bailey Street, Manchester, in collaboration with the late Mr. Sturgis Meek; and introduced revolving capstans and power-cranes with the effect of greatly expediting the loading and despatch of goods at those important centres. At an earlier date, about 1848, he spent much time in developing a sewing-machine, but the success was purely mechanical. Cord power-cranes on Ramsbottom's principle, hydraulic-press plants for baling raw cotton

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and piece goods, and slate-working machinery were important features in the business of the firm. In regard to mill-gearing, which was the original backbone of the business, Mr. Hopkinson was recognised as a leading and most trustworthy practical expert. He was consulted by many of the firm's customers as to their mills and works, and frequently designed buildings for them. A fire-proof spinning-mill for Messrs. John Dewhurst & Sons, of Skipton, which is a conspicuous object from the Midland Railway, and an eight-storey warehouse and other extensions for the York Street Flax Spinning Company, of Belfast, may be mentioned as examples. As a consulting engineer his practice followed substantially the same lines, with the addition of expert evidence before Parliamentary Committees, in the law courts, and in valuation cases.

In 1866 he became a Director and Vice-Chairman of the Carnforth Hematite Iron Company, and continued as Chairman and Vice-Chairman to take an active guiding interest in its affairs until his death. In 1874 he became Chairman of the Chatterley Iron Company, and devoted much attention to the improvements of the siding and mechanical arrangements of the various collieries and to the provision of adequate access by private lines to the various sale yards of the Company. The financial difficulties of the Company, arising from the excessive royalty obligations undertaken before his chairmanship, were a less agreeable and more serious burden, from which he was only relieved by the liquidation of the Company.

Mr. Hopkinson devoted a very large share of time to the public service. Entering the Manchester City Council by an unopposed election in 1861, he was periodically re-elected unopposed until he became Alderman in 1872. That office he filled until death terminated a continuous municipal service of more than forty years. He was Mayor for the municipal year 1882–83. His engineering and business experience rendered his services of great value in the Council and on the various committees of which he was a member. The improvement of the River Medlock was the first subject he took up in the Council, having personal experience of the damage done by its periodical floods. By the clearing of its bed, building side retaining-walls, and especially by the substitution of tilting weirs for fixed weirs, all of which were carried out under his guidance, a complete cure was effected at a far less cost than the relief tunnel proposed by the professional advisers of the Corporation. As a member of the Gas Committee he settled many

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miles of frontier with Stockport and other authorities, and took a prominent part in regard to the Bradford Road works, from the negotiations for the purchase of the land to the laying out of the main lines of the works. In street improvements he devoted much time to the widening of existing thoroughfares and the provision of new arteries for traffic. On committees less cognate to engineering matters he also did good work, notably, the Free Libraries, the Watch and its Fire Brigade sub-committee, the Finance, the Ship Canal, the Town Hall and the Art Gallery Committee, of which he was Chairman for many years. In connection with the Independent Church of Rusholme Road, Manchester, and its Sunday School, he was for many years an active worker as Deacon and Sunday School Teacher and Superintendent. Of his ideal family life it is not necessary to write here. His death took place on the 14th March, 1902.

On the 14th April, 1885, he was elected a Member of the Institution, of which his sons, the late Dr. John Hopkinson and Charles Hopkinson, were then Members, whilst his son Edward became a Member subsequently.

WILLIAM RICH HUTTON, born at Washington, U.S., on the 21st March, 1826, obtained his first professional experience on survey work for the United States Engineers. From 1854 to 1861 he acted as Divisional Engineer on the Washington Aqueduct, being promoted to the post of Chief Engineer in the latter year. In 1866 he constructed the Annapolis Waterworks, and in 1869, as Chief Engineer of the Chesapeake and Ohio Canal, he completed a masonry dam across the Potomac and other important works. He acted as Consulting Engineer to the Canal until 1880. From 1871 to 1873 Mr. Hutton acted as Chief Engineer on the construction of the Western Maryland Railroad, and from 1876 to 1879 he was engaged in designing and directing the construction of locks and movable dams for the improvement of the Kanawha River.

In 1880 Mr. Hutton moved his offices to New York City, and subsequently became Consulting Engineer for the New Aqueduct, for the Colorado Midland Railroad, and for other undertakings. From 1886 to 1889 he was Chief Engineer of the beautiful Harlem River Bridge, known as the "Washington" Bridge, and later he occupied a similar post on the Hudson River Tunnel and served

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on the Commission for the improvement of the Columbia River. He was a Member of the American Society of Civil Engineers, of which he was Vice-President in 1896–97, and of the Société des Ingénieurs Civils de France. Mr. Hutton died at his residence, The Woodlands, Clopper, Montgomery County, Maryland, on the 11th December, 1901.

He was elected a Member of the Institution on the 2nd December, 1890.

WALTER ROBERT KINIPPLE, born at Limehouse on the 31st July, 1832, was the son of Mr. George Topliff Kinipple, who was engaged in shipbuilding on the Thames for many years. His family, of Danish origin, was connected with shipping and shipbuilding for generations, and some 160 years ago one of his ancestors constructed a bascule bridge over the harbour at Copenhagen which is still known as the Kinippel Bridge.

In 1846 the subject of this notice was articled to the late Mr. J. B. Redman, who had been Chief Assistant for a number of years to Mr. James Walker, Past-President. The period of pupilage lasted seven years, and was followed by a term of five years as an assistant to Mr. Redman, during which period he was engaged on the drawings and construction of Greenwich Pier, Gravesend Pier, Mowlem's Wharf, Tidal Docks at Greenwich, and other works.

In 1858 Mr. Kinipple commenced to practise on his own account, and from that date until he retired in 1896 he had a busy and prosperous professional career. His engineering training had been principally in connection with marine works, and to that class of work he devoted himself largely, but not exclusively, throughout his subsequent career. Thus, after starting on his own account, he had overhauled and reconstructed in a few years a large number of graving docks and riverside properties on the Thames, amongst which may be mentioned Princes Dock, King and Queen Dock, Limekiln New Dock (one of the largest then constructed), Bull Head Dock, Commercial Dry Dock, North Woolwich Dock, Regent's Dry Dock, East Greenwich Graving Docks, Union Docks, Nelson Dock, Limehouse Dry Dock, Cubitt's Town Dock, and Deptford Green Dock. During that period, 1858–67, he was also engaged actively in the preparation for Parliament of schemes of railway works projected for the eastern and southern counties of England.

Between 1855 and 1860 Mr. Kinipple spent considerable

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time in experimenting with Portland cement, as to the uses to which it might be applied, especially in connection with marine works, in stopping leaks and cementing materials together under water. These experiments proved useful to him at the time in stopping leaks in dams and dock entrance works, and subsequently were of much service in carrying out dock, harbour and breakwater works.

Between the years 1860 and 1890 Mr. Kinipple submitted competitive designs for a number of works amongst which may be mentioned the harbours of St. Helier's, Jersey, Greenock, Quebec, and Poole. The adoption of his design for the new harbour works at Greenock was the origin of his long connection with the Harbour Board there, from 1868 till 1887, during which period he acted as Chief and Consulting Engineer for the Greenock Harbour Trustees, constructed the new harbour works at the east end of the town and remodelled the old works. These works were fully described in a Paper[1] he contributed to the Institution in 1897, so that detailed reference to them need not be made here. Previous to his connection with Greenock he had designed and patented a travelling caisson, with lowering deck for harbour purposes. This caisson serves the double purpose of dock gates and opening bridge for road and railway traffic across a dock or harbour entrance. Three of these caissons are in use at the Greenock Docks, one at the Clyde Navigation Docks, Glasgow, and six at other ports in various parts of the world. In the reconstruction of the West Harbour at Greenock, Mr. Kinipple spanned the entrance by a bridge constructed on the same principle as the caisson, but with open instead of closed sides, thus allowing free passage of the tidal waters to and from the harbour. This bridge, which provides railway communication across the harbour entrance, is a careful adaptation of design to site and requirements. The travelling caisson and bridge are described fully in the Paper above referred to.[2]

Mr. Kinipple's official connection with the Greenock Harbour Trustees terminated in 1887, on the completion of the new works, after which he devoted himself to his London practice.

The works carried out at Quebec Harbour, in accordance with the competitive designs of Mr. Kinipple, were described in Papers contributed to the Institution by Mr. St. George James Boswell[3]

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[1] Minutes of Proceedings Inst. C.E., vol. cxxx., p. 276.
[2] *Ibid*, p. 287. [3] *Ibid*, vol. lxiii. p. 265.

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and Mr. Woodford Pilkington.[1] A masonry graving dock was also constructed at Quebec, of a length of 500 feet by a width of 100 feet, and the dock entrance was closed by one of Mr. Kinipple's caissons. The climatic conditions in Canada are much more severe than in England, and the system of execution of work requires to be modified considerably. The modification which Mr. Kinipple adopted was that of cribwork construction.

At Esquimalt in British Columbia he constructed for the Canadian and Imperial Governments a graving dock for men-of-war and merchant vessels. This dock, 451 feet long by 90 feet wide at coping, with 41 feet depth of water on cill at high water of ordinary spring tides, is constructed of masonry set in Portland cement mortar and faced with ashlar. For Newfoundland he and Mr. Morris surveyed and prepared drawings and specifications for about 100 miles of railway, and reported on water-supply and sewage-disposal. Mr. Kinipple's advice was also sought by Governments and Harbour Authorities in other colonies, especially with regard to dredging plant, and he acted as Consulting Engineer for such to the Governments and Harbour Boards of New South Wales, Victoria, South Australia, New Zealand, and Aden.

He was consulted by the Aberdeen Harbour Trustees with respect to the construction of their new graving dock, and the proposed National Harbour of Refuge for which a Government enquiry was held. For the Wick Harbour Trustees he rendered secure the breakwater which had been endangered by a severe storm, and furnished designs for a complete scheme of harbour works with breakwater protection. He constructed a fishing harbour at Girvan in Ayrshire, consisting of two sheltering moles on breakwaters with inside quay-works, and dredged channel-way. At Llanelly he laid down the lines of training wall for the improvement of the channel-way in the Burry Estuary and constructed a considerable length of the training wall. He also constructed the Llanelly and Mynydd Mawr Railway for the development of part of the South Wales coalfield.

In 1889 he was instructed by the Harbour Committee of the States of Jersey to extend the Hermitage Breakwater at St. Helier's, reconstruct the Victoria landing stage and the North Pier, and provide by dredging increased depth of water in the harbour, and in the channel-way outside the harbour. In the

[1] Minutes of Proceedings Inst. C.E., vol. cxxxix. p. 286.

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execution of these works he carried down all foundations, whether of breakwater or quay-walls, to the rock through varying thicknesses of overlying sand and clay up to as much as 22 feet in depth below the sea or harbour bottom. Both in the breakwater and quay-walls a system of concrete blockwork construction was adopted, each block having projections and recesses which fitted into corresponding recesses and projections in adjoining blocks. The external joints of the work were caulked with strips of canvas, and neat Portland cement grout was then passed down through an iron tube from above water-level, which cemented the blocks firmly together into one mass. A level bed on the irregular surface of the rock was previously prepared for the reception of the blocks by depositing loose rubble and shingle within a barrier of bags of concrete; the surface of the rubble and shingle was levelled off by divers with levels and long straight-edges, and the loose materials then cemented into a solid mass with neat Portland cement grout. The system proved to be thoroughly effective in practice, and since its application for breakwater and quay-wall purposes in Jersey it has been employed with satisfactory results by other engineers. Grouting for various purposes had been employed by Mr. Kinipple since 1858, but the first breakwater and quay-wall works where it was used systematically and on a large scale were at the Jersey Harbour works in 1887. In the previous year he contributed to the Institution a description of these methods in a Paper entitled "Concrete-work under Water."[1]

At Poole Mr. Kinipple advised the Harbour Board as to the steps to be taken to increase the depth of water over the bar and improve the channel-way to the harbour; and he carried out the reconstruction of the quay-walls along the frontage of the town, and provided an increased depth of water. In the construction of the new quay-walls at Poole, and of the new quay-wall, over 2,000 feet in length, at Great Yarmouth, for which he acted as Consulting Engineer to the Town Council, he adopted the same method as that employed at Jersey.

Other works which Mr. Kinipple carried out were a large graving dock at Blackwall for Messrs. Green; a graving dock at Limehouse 440 feet long for Messrs. Fletcher Son and Fearnall; the enlargement of Renfrew Harbour, the construction of a large sugar factory at Silvertown for Messrs. Lyle, and piers at various

[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 65.

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places. He was also consulted in connection with the proposed Vardar reclamation and irrigation works in Turkey, the Cullera Harbour and Railway in Spain, and numerous other projects.

Throughout his career Mr. Kinipple displayed much ingenuity in mechanical appliances, and introduced various improvements in connection with dredging plant, one of which was the system of stern-well hopper-dredger, whereby a full instead of a divided bow was obtained. This arrangement is now largely used. Another invention related to dredger-buckets, whereby the bucket was made in three parts, each easily and quickly replaceable from spare parts kept in stock, in the event of a breakdown or of becoming worn out. A further design relating to dredgers was for a double-ladder dredger having a circumferential movement and mounted on a circular vessel.

In 1874 Mr. Kinipple associated with him the late Mr. William Morris, and all works, except those in Scotland, were carried out jointly from that date until the death of Mr. Morris in 1886. In 1891 Mr. William Jaffrey, who had for a number of years been Chief Assistant to Mr. Kinipple, became a partner and was associated with him in the execution of all works until Mr. Kinipple's retirement on considerations of health in 1896.

Although withdrawn from active pursuit of the profession, his interest in engineering questions was fully maintained, and his advice from time to time sought and given. Thus for the Egyptian Government he went twice to Cairo, examined the Damietta and Rosetta dams of the Nile and the Shubrah Locks, the leakages under the foundations of all of which had caused serious trouble, and reported on the steps to be taken to remedy the defects. He recommended securing the foundations of the work, and cutting off the leaks and runs of water by stock-ramming with clay, and hydraulic lime or cement. His advice was adopted. Bore-holes were put down through the masonry piers for the purpose, and the stock-ramming proved to be most effective.

In 1899 he visited St. John's, New Brunswick, to advise with respect to a graving dock 800 feet long for accommodating the largest liners and men-of-war.

Mr. Kinipple took an active interest in all matters relating to the practical side of engineering. He was skilful in designing and executing works, and fertile in expedients for overcoming difficulties. He contributed to technical journals and lectured to the Royal Engineers at Chatham on Subaqueous Foundations. In temperament he was of a genial disposition, fond of social

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intercourse, and had a wide circle of friends. Amongst engineering friends he liked specially to discuss intricate or awkward engineering problems, and was very ready and resourceful in providing practical solutions.

After retiring in 1896 he lived at Brighton. On the 18th November, 1901, when apparently enjoying excellent health, he had a paralytic seizure, and passed away on the 25th of that month without having recovered consciousness.

Mr. Kinipple was elected a Member of the Institution on the 7th February, 1865.

ALGERNON LEVENTHORPE, son of the late Rev. T. W. Leventhorpe, was born on the 24th April, 1858, and, after passing through the Royal Indian Engineering College at Coopers Hill, was appointed an Assistant Engineer in the Public Works Department of the Government of India in 1879. He was posted to the Buildings and Roads Branch, and was employed in Berar until 1890, in Beluchistan from 1890 to 1892, and in Burma from 1893 until his death, rising in the meantime through the various steps to the position of Executive Engineer, 1st-grade. In 1899 he was appointed Assistant to the Chief Engineer and Under-Secretary to the Government of Burma in the Public Works Department. Mr. Leventhorpe died at Rangoon on the 3rd July, 1902, aged 44.

He was elected an Associate Member of the Institution on the 2nd December, 1884, and was transferred to the class of Members on the 18th December, 1900.

ALEXANDER GRAINGER LINN obtained his first engineering experience as a pupil at the Railway Foundry, Leeds. On the expiration of his pupilage he was engaged for four years at the Grimsby Docks and at New Holland, Hull, and was subsequently employed for a similar period, from 1854 to 1858, as agent to the late Mr. J. Towlerton Leather on the contract for the Nene Valley Improvement Works at Wisbech. On the completion of those works he was for two years in charge of the construction of a section of the Severn Valley Railway, and from 1860 to 1863 he was similarly employed on the Western Division of the

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Metropolitan Railway. Mr. Linn was next engaged for a year on the works connected with the Middle Level Inundation under Sir John Hawkshaw, Past-President, and from 1864 to 1866 as Resident Engineer on the Edgware, Highgate and London Railway. From 1867 to 1878 he had offices in Westminster, and in 1879 he removed to Liverpool. During the latter years of his life, Mr. Linn did not carry out engineering works. He died at 121 Upper Parliament Street, Liverpool, on the 31st March, 1902.

Mr. Linn was elected an Associate of the Institution on the 2nd December, 1856, and was transferred to the class of Members on the 24th April, 1866. He was a generous supporter of the Benevolent Fund, which under his will has been left the residuary legatee of his estate.

ROBERT PATRICK TREDENNICK LOGAN, born near Ballyshannon, County Donegal, on the 24th November, 1852, was the eldest son of the late Lieutenant-General Logan, C.B., formerly of the 57th Regiment, "the Die-hards," a member of a numerous Berwickshire family. After being educated at Cheltenham College the subject of this notice qualified for admission into the Corps of Royal Engineers, but, losing his left hand a few weeks afterwards, was prevented from adopting the military profession. It was then determined that he should become a Civil Engineer, and in 1873 he was articled to the late Mr. P. J. Margary, then Engineer of the South Devon and Cornwall Railways, under whom he was employed on the St. Ives branch of the West Cornwall Railway. From 1877 to 1881 he acted as Resident Engineer on the construction of the Sligo, Leitrim and Northern Counties Railway, holding for part of that time the post of Permanent Way Engineer and Locomotive Engineer.

Mr. Logan next had charge for six years of the construction of the Carrickmacross branch of the Great Northern Railway of Ireland, under Mr. W. H. Mills. He then began in 1887 a private practice in Dundalk as a Civil Engineer and Architect. In that capacity he prepared plans for the proposed Armagh and Keady Light Railway, and for numerous works. Although having only the use of his right hand, Mr. Logan was a practical mechanic, had steam workshops on his premises, and an engine which he constructed himself obtained the first medal and diploma of merit at

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the Irish Artizans' Exhibition in 1884. Mr. Logan died at Dundalk on the 26th April, 1902.

He was elected an Associate of the Institution on the 5th February, 1878, was subsequently placed in the class of Associate Members, and was transferred to full Membership on the 22nd April, 1890.

DAVID McMORDIE, born on the 26th November, 1846, was the third son of the late Rev. J. A. McMordie, of Seaforde, County Down, Ireland. He was educated at the Royal Academical Institution and at Queen's College, Belfast, and obtained the Degree of Bachelor in Engineering from the Queen's (now Royal) University of Ireland. In 1869 he obtained a high place at the competitive examination for the Indian Public Works Department, and elected to serve in the Punjab. He was therefore posted to the Irrigation Department in that province, and served for some time as Assistant Engineer on the Bari Doab Canal, and subsequently, under Mr. H. Garbett and Mr. W. Andrews, on special survey work in connection with the River Indus. In 1874 he was temporarily employed on extensive famine relief works on the Sone Canal in Bengal; but after his return to the Punjab at the end of that year, his health broke down, and early in 1875 he was obliged to take sick leave. Returning to India in the beginning of 1877, Mr. McMordie was sent to take charge of extensive famine relief works in the Bombay Presidency, and on their completion he was posted to similar work in Madras. Subsequently he returned to the Punjab, where he was placed in charge of work then in progress on the Western Jumna Canal. In 1879 he decided to resign the Indian Service and go to Australia.

Early in 1880 Mr. McMordie arrived in Sydney, and shortly afterwards he was appointed Resident Engineer on the Sydney Sewerage Works under the late Mr. W. C. Bennett. He was soon promoted to the rank of District Engineer, and while in that position he commenced and carried to completion, among other works, the main outfall sewer, which included a tunnel 4½ miles in length. Whilst holding the office of District Engineer on the Sewerage Works, Mr. McMordie was appointed a Member of the Royal Commission on the Conservation of Water throughout New South Wales. During the inquiries conducted by that Commission, he took a prominent part at its meetings, and went with the

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Commission through a great part of the Colony. At the beginning of 1890, Mr. McMordie was appointed Superintending Engineer in the Water Conservation Department, and held that office till his retirement in 1896. For some time prior to this his health had been in an unsatisfactory state, and though he rallied considerably after he retired, his recovery was only partial and temporary, and on the 11th February, 1902, he died, after a lingering illness, at Roshnara, Willoughby, Sydney.

Mr. McMordie was elected a Member of the Institution on the 19th May, 1885.

CHARLES YELVERTON O'CONNOR was born in Ireland in 1843. His early education was obtained at the Waterford Endowed School. At the age of seventeen he was apprenticed to Mr. John Challoner Smith, with whom he continued until 1862, and was subsequently engaged in engineering work in connection with the Roscrea to Birdhill, Banbridge to Ballyroney and other railways in Ireland until 1865, when he emigrated to New Zealand. There he was first employed as an Assistant Engineer on the construction of the coach road from Christchurch through the Otira gorge to the Hokitika goldfields. He was promoted from time to time, and was Assistant Engineer in the province of Canterbury from 1866 to 1870. At that time the west portion of Canterbury was constituted a separate county, and Mr. O'Connor was appointed its Engineer. Subsequently he was District Engineer, under the central Government of New Zealand, for the county of Westland, and later for the Canterbury provincial district. In 1874 he received the appointment of District Engineer for the combined Westland and Nelson districts, a position which he retained until 1880. By permission of the Government of New Zealand he also acted as Consulting Engineer for the county of Westland, and to the Hokitika Harbour Board. In 1880 Mr. O'Connor was appointed Inspecting Engineer for the whole of the Middle Island of New Zealand, and he retained that office until 1883, when the Minister for Public Works, realising the necessity of having an experienced engineer at his right hand to advise on all matters affecting Public Works, selected Mr. O'Connor, who was removed to Wellington as Under Secretary for Public Works for New Zealand, and acted in that capacity until

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May 1890, when he was appointed Marine Engineer for the Colony.

In April, 1891, Mr. O'Connor accepted the appointment of Engineer-in-Chief of Western Australia. That position included the Acting General Managership of Railways, which Mr. O'Connor held until December, 1896, when, at his own request, he was relieved of that office, in order that he might devote the whole of his attention to his engineering duties.

As Engineer-in-Chief of Western Australia, Mr. O'Connor designed a large number of engineering works throughout the State. Two works call for special mention: the Fremantle Harbour Works, and the Coolgardie Water Scheme. The Fremantle Harbour Works, estimated to cost £800,000 in securing Parliamentary authority for which Mr. O'Connor gave evidence in an able and masterly way, were commenced in November, 1892. The works, now nearly finished, consist in the formation of a safe and commodious harbour in the mouth of the Swan River, capable of receiving and berthing the largest mail steamers at all states of the tide and in all weathers. For this purpose North and South Moles, of limestone rock and rubble, were projected to lengths of 4,800 feet and 2,040 feet respectively, and the sand and sandstone rock dredged to a depth of 30 feet at low water. The length of the Inner Harbour is about 5,280 feet, with a width at its broadest part of 1,400 feet. A wharf about 5,625 feet in length has been constructed at the South Quay, also a wharf at the North Mole, 1,000 feet, and at the South Mole, 300 feet in length respectively. Wharfage at the south side is also being erected to a length of 3,478 feet. At the north quay three jetties are provided for, running obliquely from its face, each 400 feet in length. The reclamation of 54 acres for the quay on the south side, and 20 acres on the north side are also provided for. It is likewise intended to provide a graving dock and patent slip. Fremantle is now the first port of call and the last of departure for English vessels, instead of Albany (King George's Sound), and the harbour has given the utmost satisfaction to all concerned.

The Coolgardie Water Scheme for supplying water to the principal goldfields of Western Australia—estimated to cost £2,500,000—proposes to deliver to the goldfields of Coolgardie and surrounding districts a supply of 5,000,000 gallons per day of fresh water, to be pumped from a storage reservoir on the Helena River, about 23 miles from Perth, and 328 miles from Coolgardie. The works contemplated, and now in course of construction,

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consist of a storage reservoir on the Helena River, to hold 4,600,000,000 gallons of water; pumping installations at eight stations; a main conduit of steel pipes, 30 inches in diameter; receiving tanks, minor reservoirs, and service reservoirs; and distributing pipes on the goldfields.

In connection with the Railways of Western Australia, Mr. O'Connor was responsible for several improvements. Some of the gradients are 1 in 25 to 1 in 30, and Mr. O'Connor had surveys made of a number of deviations of the line, and alterations of gradients made so that the ruling gradient should not exceed about 1 in 50; he also had relaid 100 miles of line with heavier rails, 60 lbs. to the lineal yard, and imported powerful goods engines. Had this not been done promptly the railway traffic would have been most seriously congested at many points as a natural consequence of the rapid progress of the Colony.

Other works designed and carried out by Mr. O'Connor, such as wharves, jetties, bridges and harbours, are too numerous to mention here. In him the Colony of Western Australia has lost a man who, after Sir John Forrest, was, it is generally conceded, foremost in its development.

The Companionship of the Order of St. Michael and St. George was conferred on Mr. O'Connor in 1897. In January of that year he came to London in connection with the Coolgardie Water Scheme, and returned in the following September. On that occasion he was specially commissioned to visit the old country to confer with, and to supply data with reference to the water scheme to the Board of Engineering Experts appointed to deal with the scheme. He was also instructed by the Colonial Government to visit the principal engineering establishments, harbour works, docks, light railway systems, etc., in England and on the Continent, with a view to gaining up-to-date information as to the best means of handling cargo in harbours and the construction of harbours and harbour-appliances.

Mr. O'Connor was a man of high character and rare ability, with indefatigable mental energy and strong powers of analysis and criticism. He had a wonderful grasp of his subject, yet was capable of analysing the minutest detail—a very rare gift. He had also energy and determination, sound judgment and prompt decision. No amount of work or engineering difficulties discouraged him. He never spared himself, and thus inspired his subordinates with the same enthusiasm and devotion to work. In his private life he was genial and hospitable, and never forgot

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old friends. He possessed a high sense of honour, and never used his public position to enrich himself. His whole life and energies were expended on the great works he had undertaken. The deepest sympathy and most profound regret were universally expressed in Western Australia at the untimely loss of one so well known and highly esteemed both in public and private circles. He died at Freemantle, Western Australia, on the 10th March, 1902, in the fifty-ninth year of his age.

Mr. O'Connor was elected a Member of the Institution on the 6th April, 1880.

JOHN ROBINSON[1] died on the 9th July, 1902, at his residence, Westwood Hall, Leek, in North Staffordshire, after an illness of some weeks. The mention of his name recalls to memory an eminent mechanical engineer, identified throughout his generation with the construction of locomotive engines in every variety and for all quarters of the globe, as a partner in the Atlas Works of Messrs. Sharp, Stewart and Company, originally in Great Bridgewater Street, Manchester, and now at Springburn, Glasgow. At his advanced age he had naturally outlived most of the contemporaries of his busier engineering years, and even many of the younger generation which furnished the host of pupils who enjoyed the advantage of serving their apprenticeship under his able and sound training.

He was the son of a banker at Skipton, where he was born in March, 1823, and received his earliest education at the Skipton Grammar School. Thence he was sent to a physical-science and general school in Manchester, conducted by Charles Cumber, who was an intimate friend of John Dalton, the originator of the atomic theory in chemistry. His boyhood thus came under the joint influence of Dalton and of Peter Clare, whereby his mind may possibly have been turned to the subjects of which he afterwards obtained so thorough a grasp. After further study at the Wakefield Proprietary School, he was apprenticed at the age of sixteen to Mr. Richard Roberts, of the firm of Sharp, Roberts and Company locomotive-engine builders, Atlas Works, Manchester. After th dissolution of this partnership in 1843, he joined Messrs. Sharp in the firm of Sharp Brothers and Company, which in 1852 was

[1] Reprinted, by permission of the Editors, from *Engineering*, 18 July, 1902.

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changed to Sharp, Stewart and Company, on the accession of the late Mr. Charles P. Stewart, who was the same age as himself. Being a practical workman in the fullest sense, Mr. Robinson took entire charge of the workshop department, diversifying this supervision by numerous business visits to the Continent, where he made the acquaintance of many of the leading locomotive engineers.

So closely were his energies devoted to the practical pursuit of his engineering avocations, that the Paper he read to the Institution of Mechanical Engineers in January, 1860, was possibly his earliest contribution to the literature of the profession. The subject was the Giffard injector for feeding steam boilers, which at that time was attracting special attention, both from the importance of the object aimed at, and from the success with which this object had already been attained, as well as from the novelty and singular nature of the action of the instrument, and from the great simplicity of its arrangement. On the announcement of the invention in France, its practical value was promptly recognized by him; and the manufacture and introduction of the injector were undertaken by his firm. After they had first worked out the details of the sizes and shapes of the conical nozzles, and the relative areas of steam and water passages, one of their engineering assistants was sent to visit all the leading locomotive and other engine works, with a view to the practical and extensive use of the injector, and its substitution in place of the feed-pump. Mr. John Barber, who was entrusted with this duty, acquired a wide renown as "Injector Jack," before settling in Leeds. As the instrument was a French invention, it was made throughout to millimetre dimensions; an internal gauge was used, consisting of a round steel template, tapering 1 millimetre in diameter in every 25 millimetres, or about 1 inch of length; this was divided into inches and tenths, enabling the men to work to $\frac{1}{10}$ millimetre or $\frac{1}{250}$ inch. When the same subject was discussed five years later, at the Institution of Civil Engineers, Mr. Robinson was able to state that all the new engines on the London and North Western Railway were made to depend entirely upon the injector for the feed-water, and there were no pumps to the boilers.[1] In the following year, 1866, he read a second Paper to the Institution of Mechanical Engineers, describing the arrangement of self-adjusting injector devised by Mr. William Sellers, of Philadelphia. He added

[1] Minutes of Proceedings Inst. C.E., vol. xxiv. p. 218.

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that the increase in maximum delivery, due to improvements in the proportions of the injector subsequent to its introduction, had been much more considerable in England than in France; the greater degree of success attained in England, particularly at higher pressures, was to be attributed mainly to the adoption of a larger proportionate sectional area for the steam cone.

To the Institution of Civil Engineers he contributed in 1873 a Paper [1] on modern locomotives, describing six prominent examples of passenger, goods, and tank engines, designed with a view to economy, durability and facility of repair; respecting each he gave some particulars of the duty performed, and of the cost of repairs. The tendency in the manufacture and use of locomotives, he rightly pointed out, had been to simplify their construction, and to secure, by the adoption of more durable, even if more expensive, material, a more serviceable engine, which, taking into account the continually increasing amount of work imposed upon it, was doing its work with considerably greater economy than formerly.

Having been a Member of the Institution of Mechanical Engineers from 1859, a Member of Council from 1866, and a Vice-President from 1870, he was elected President in 1878, and again in 1879. In his Presidential Address in 1878, delivered at the Paris meeting of the Institution on the occasion of the International Exhibition of that year, he combated the bugbear of "over-production" in engineering, in its relations to agriculture, manufactures, transport, and warfare; urging that, at times when the law of political economy—that supply and demand must of necessity adjust themselves to each other—seemed to have lost its place in the engineering world, engineers should nevertheless look around courageously, and take so comprehensive a survey of their position as to encourage them to hold on their course with vigour. In 1879 he devoted his address to the consideration of cheap internal transport as a necessity for the prosperity of a country. At that time the cycle was still so great a rarity as to be looked upon more as a curiosity than as a practical means of locomotion. Even electric lighting was in an infantile state, while the motor car, if dreamt of at all, was a dream of which the most far-seeing minds could but indistinctly discern the dim fabric. Hence his suggestion, appropriate to the conditions then obtaining, of roadside railways or tramways for facilitating transport in districts devoid of adequate means of communication; and he

[1] Minutes of Proceedings Inst. C.E., vol. xxxvii. p. 1.

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dealt with various practical points bearing upon the realization of such a plan, as well as with the collateral advantages of cheapening transport.

Perhaps as good an illustration as any of his shrewd mechanical insight is furnished by his attitude towards the Le Chatelier counter-pressure steam brake. While he had at the outset seized upon the merits of the Giffard injector, and had made so great a success of it, he held aloof from similar association with the Le Chatelier brake, notwithstanding the fame of the inventor and the powerful and persistent advocacy of so eminent and scientific an engineer as Sir William Siemens. Many of the locomotives he built were fitted with the arrangement, at the desire of the railways ordering them; but, while welcoming their orders, he did not urge its adoption as he had done that of the injector; and on some lines on which the counter-pressure brake had been introduced it was ultimately discarded.

On the occasion of the summer meeting of the Institution of Mechanical Engineers in Paris in 1878, during his presidency, he was elected an honorary member of the Société des Ingénieurs Civils de France.

In 1863, when the firm of Sharp, Stewart & Co. was converted into a company, he became Vice-Chairman and afterwards Chairman of the Board of Directors. When, in 1888, the business had outgrown the Manchester premises, the locomotive and machine-tool works were removed to the Clyde, and amalgamated with the Clyde Locomotive Works at Springburn, Glasgow. There the active participation in their control, from which he had retired some sixteen years earlier, passed into the hands of his son, Mr. John Frederick Robinson.

Having been one of the guarantors of the original Great Exhibition in 1851, he was more or less connected with many of the subsequent similar international exhibitions. At the Paris Exhibition in 1878 he was a member of the jury for prime movers, and also of the international jury for engineering excellence in the exhibition. In 1867 he gave evidence before the commission appointed to enquire into the organization of rules of trades unions and other associations; the report thereon was followed by the legalization of such unions. Among the many services he rendered to the cause of education were the responsibilities he undertook as trustee of the Owens College, Manchester.

In 1867 he took up his residence at Westwood Hall, which he purchased, with 700 acres of land adjoining. There he lived thence-

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forth, except when latterly wintering at Torquay for the benefit of his health. In 1869 he became a County Magistrate, and later, Deputy Lieutenant. In 1882 he filled the office of High Sheriff of Staffordshire. In matters of local government and education, and other interests, he took an active and prominent part. From his early days he paid much attention to the cultivation of forest trees, and acquired an excellent knowledge of timber; even in his later years the pruning and felling of trees formed his chief exercise. In the local Press his death is announced as that of the "Squire of Westwood and First Gentleman of Leek, full of years and full of honours"; and the warm tribute paid to his character and memory has its echo in the hearts of the large circle of engineering friends who appreciate his sterling worth, whether as a man or as an engineer.

Mr. Robinson was elected a Member of the Institution on the 9th April, 1872.

THOMAS RUMBALL, a son of Mr. Thomas Rumball, of Epping, was born on the 5th October, 1824, and served his engineering pupilage to Sir Marc Isambard Brunel on the construction of the Thames Tunnel. After having been engaged for some years on railway surveys in Portugal, he was appointed in 1852 Engineer-in-Chief of the Peninsula Railway of Portugal, now forming part of the Royal Portuguese Railways.

Mr. Rumball's connection with Portugal and Spain continued for over forty years, during which time he was engaged in the prosecution of public works in those countries, amongst which may be mentioned the survey of the line from Lisbon to Oporto, a scheme for supplying Oporto with water, the survey of a line of railway from Barcelona to Madrid, and the Alcoy and Villar Railway. For his services rendered to Portugal he was, in 1889, publicly thanked by the King and created a Knight Commander of the Order of Christ.

In 1862 Mr. Rumball was appointed Engineer-in-Chief of the Buenos Aires Great Southern Railway, in which capacity he constructed the first 100 miles of that line. On the completion of that contract he constructed the Para Gas Works, the São Paulo Gas Works, and the Parahibo Bridge over the river of that name for the Brazilian Government.

At the time of the Russo-Turkish War and the Treaty of San

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Stefano, Mr. Rumball was induced by the late Sir W. P. Andrew to take an interest in the construction of an overland railway route to India, and took part in a mission to Constantinople in 1878, which succeeded in securing from the Turkish Government for an English syndicate the control of the railway from Haida-Pacha (Scutari) to Ismid, with the valuable privilege of extending the line to Angora and Bagdad. That railway now forms part of the Anatolian line controlled and operated by German capital, and destined to be the first section of the long-contemplated railway to India. Mr. Rumball was in active control and management of this line for three years, during which time he became thoroughly acquainted with Asia Minor and its resources. He prepared plans for supplying the City of Constantinople with water, an undertaking subsequently carried out by a French company at a cost of £800,000. At the time of the demonstration of the English fleet at Besika Bay, he received the thanks of the War Office for his reports and information as to the Heraclea coal mines in Asia Minor and the coaling of the English fleet. In the year 1885 he became interested in the concession for a railway from Delagoa Bay through Portuguese East Africa to the Transvaal frontier, and took part in a mission to Lisbon which obtained from the Portuguese Government such favourable modifications of the original concession as to render practicable the construction of the railway by English capitalists. In conjunction with Sir Thomas Tancred, the contractor, he completed the railway in six months, fulfilling the terms of the concession, and so saving to the English company for the time being this valuable undertaking.

Mr. Rumball was one of the founders, with the late Mr. Gerstenberg, of the Corporation of Foreign Bondholders, to which he acted as consulting engineer and as a member of its Spanish and Turkish committees for several years. He was a man of great energy and industry, most careful of the interests committed to his charge, and especially of the sound character of the many enterprises to which he committed his name. He married Miss M. A. Medlicott, a daughter of Mr. E. Medlicott, banker, of Lisbon, in the year 1855. Mr. Rumball died at Brondesbury on the 28th February, 1902.

He was elected an Associate of the Institution on the 2nd May, 1854, and was transferred to the class of Members on the 10th April, 1866.

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JAMES SHAND, who died at his residence in Elm Park Gardens, London, on the 10th June, 1902, was born at Edinburgh in 1823. After being educated in that city he acquired a varied knowledge of mechanical engineering as a pupil of Mr. James Slight, then engineer to the Highland and Agricultural Society of Scotland. His successful management of the business of Mr. W. J. Tilley, fire-engine maker and hydraulic engineer, of Blackfriars Road, London, whom he joined in 1845, led to his taking the senior position in the firm of Shand and Mason (now Shand, Mason and Company), formed on the retirement of Mr. Tilley at the end of 1850.

Although his early attention was directed to the improvement of the manual fire-engine, as evidenced by the exhibits of the firm at the Great Exhibition of 1851, Mr. Shand was best known in connection with his efforts in bringing the steam fire-engine to its present state of practical utility. The first land steam fire-engine was constructed by Braithwaite in 1830, but its recognition in London as a valuable fire brigade appliance did not take place until 1852, when Messrs. Shand and Mason were instructed by the then London Fire Brigade to apply steam-power to the largest of the floating manual fire-engines worked by 120 men. The success of this experiment was so evident that it was immediately followed by the construction of a complete self-propelling floating steam fire-engine, the first of its kind, constructed from designs furnished in competition by Mr. Shand. From 1858, when Messrs. Shand and Mason's first land steam fire-engine appeared, to the present time, the progress of these machines has been rapid, Mr. Shand's most prominent improvements having been the inclined water-tube boiler, with cylindrical tube box, by which steam of 100 lbs. pressure can be raised in a few minutes; and the treble-cylinder direct-acting steam-pump, with crank to terminate the stroke. For many years Mr. Shand was associated with the gas industry in the South of London as Director and Deputy Chairman of the Phœnix Company, and subsequently, on the absorption of the Phœnix by the South Metropolitan Gas Company, as Chairman of the united Company until 1885. In those capacities his engineering experience proved of considerable value.

He was elected an Associate of the Institution on the 1st December, 1857, and was transferred to the class of Members on the 17th March, 1874.

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JAMES CARRINGTON SIMPSON, born in 1828, obtained his early engineering experience, from 1844 to 1847, on the Manchester and Leeds Extension Railway from Miles Platting to the Victoria Station, Manchester, on the erection of the Victoria Station, and on the Northampton and Peterborough Railway from Peterborough to Oundle. He was next engaged, from May, 1848, to January, 1849, on the Haslingden branch of the East Lancashire Railway, and from the latter date to December, 1850, on the Manchester and Altrincham Railway. Mr. Simpson was then for eight years in the service of the Corporation of Manchester as Gas Engineer, in which capacity he designed and carried out the erection of No. 2 Gas Station, at that time the largest in England. From March, 1858, to September, 1866, he was Engineer-in-Chief to the Buenos Aires Gas Company, for which he designed and erected new works. During that period he also engaged in private practice in Buenos Aires, and was in 1864 Engineer of the extension of the Northern Railway of Buenos Aires from San Fernando to the River Tigre and for the wharves along the banks of the Tigre. He also prepared plans for the Buenos Aires Waterworks, which were partially carried out after he left the country, was professionally consulted by the Argentine Government from time to time, and was engaged in designing and erecting machinery for various industries in the Argentine Confederation, such as paper-making, tobacco-cutting, soap- and candle-making, hide-cleaning, etc. He was a member of the Buenos Aires Board of Public Works and a Commissioner of Patents from 1861 until he left the country in 1866.

On his return to England in 1866 he practised for four years as a Consulting Engineer in London for foreign works. In December, 1870, he went to Ceylon for Mr. Edward Woods, Past-President, as Resident Engineer on the Colombo Gasworks. While there he was also engaged on the project for the water-supply of that town, and on schemes for gas- and water-supply for the towns of Galle and Kandy.

From his return to London in December, 1872, he acted for many years as a Consulting Engineer, both for English and foreign works, in connection with railways, tramways, gas, water and sewerage. Mr. Simpson died at his residence, 46 Finchley Road, on the 19th December, 1901, aged 73.

He was elected an Associate of the Institution on the 12th January, 1864, and was transferred to the class of Members on the 17th March, 1874.

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JOHN MONTGOMERY SLEATER, who died at his residence, 4 Uxbridge Road, Surbiton, on the 6th May, 1902, aged 76, was first professionally engaged as a pupil under Mr. Nicholson, of Dublin, on various contracts in Ireland. He was then for two years in the service of the Irish Board of Works, subsequently had charge for five years of the construction of sea embankments and drainage works at Pillmore, co. Cork, and was next employed for two years on surveys for the Great Northern and Western Railways of Ireland.

Finding that the climate of Ireland did not suit him, Mr. Sleater entered the service of the Bombay, Baroda and Central India Railway Company as an Assistant Engineer in December, 1857. He was first posted to the location of that line between Dharoo and Bassein, and after twelve months was employed on the construction of the line from Surat to Baroda. Having done good work in that connection he was again posted to Bombay in 1862, and continued to take charge of the construction of the line from Bombay to Bulsar. In 1865 he went home on furlough, and on his return at the end of that year he was again posted to Bombay, where he remained for a considerable time in charge of the maintenance of the line from Bombay to Bulsar. In 1882, on the retirement of Mr. F. Mathew, he was appointed Chief Engineer of the Broad Gauge Section from Bombay to Ahmedabad, and subsequently to Rutlum. During the absence of Colonel Bisset, R.E., the Agent, on leave, he was appointed Acting Agent of the whole system from Bombay to Dhili. Mr. Sleater came home on long furlough in May, 1891, and in December, 1892, he retired from the Company's service, having completed a long and successful career. He was a man of a most genial disposition, and loved by a large circle of friends. He was an excellent man of business, and carried out thoroughly the work entrusted to him, in which task he was assisted by a willing and devoted staff.

Mr. Sleater was elected an Associate of the Institution on the 2nd February, 1858, and was transferred to the class of Members on the 17th March, 1868.

ARTHUR SMITH TRUMAN, born on the 29th August, 1833, was the eldest son of Dr. Becket Truman, of Nottingham. After serving a pupilage of five years to the late Mr. P. W. Barlow, then Engineer-in-Chief of the South Eastern Railway Company, he was

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employed from 1863 to 1868 as Resident Engineer on the section of the Lewisham and Tonbridge line. In 186 he was engaged in Transylvania for Messrs. Warin Mr. James Fforde, in laying out various portions of Hungarian Railways, and also as District Engineer o metres of the Hermannstadt branch. In 1871–73 he sup the construction of the Lisbon Steam Tramways, a Engineer for the Company, and on the completion of he was engaged from 1873 to 1875 in the construction o of the Rio Tinto Railway. In the latter year he was Resident Engineer and Traffic Manager of that line, wh held until 1877.

After being occupied both at home and abroad engineering projects, one of these being an exploratio of railway from the River Orinoco to the gold-fields Venezuela, he went to the Argentine Republic, where, to 1885, he was Chief Engineering Assistant to Mr. Thon Clarke on the Buenos Aires and Campaña Railway. employment was in Spain, from 1888 to 1891, as Residen under Mr. James Fforde, on the Bobadilla-Algeciras Ra from 1891 to 1893 he held the post of Chief Residen under Mr. Neil Kennedy, of the Murcia-Granada (Grea of Spain) Railway. Mr. Truman retired from active p work in 1893. He died at his residence, 32 Forest H Nottingham, on the 6th June, 1902.

Mr. Truman was elected an Associate of the Institu 5th December, 1871, was subsequently placed in th Associate Members, and was transferred to full Member 26th January, 1892.

ALFRED UPWARD was born in London in 1824. early age he became associated with the Chartered Ga (now the Gas Light and Coke Company), and was su appointed Engineer to that Company's City Station Lane and Curtain Road. During the 20 years Mr. Up that post he applied his inventive faculty, which was marked characteristics, to improving a number of det large gas-generating plant under his care, two specially cases being the successful application of the waste heat to the heating of steam boilers, and his apparatus for d

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tapping gas- or water-mains under pressure, which apparatus soon passed into general use. It is not possible within the limits of this notice to give details of that machine, which rapidly accomplished the making of a perfect service connection in mains under full pressure, without allowing even a momentary escape at any point of the operation. The manufacture of gas at the Brick Lane and Curtain Road Stations and their general administration, alteration, repair and extension were conducted by him with great ability, latterly under circumstances of much local difficulty. Subsequently to his connection with the Chartered Gas Company, Mr. Upward practised privately as a Consulting Engineer in Westminster until his retirement; during that time he designed numerous works for various districts and towns in the United Kingdom and abroad, in connection with which he visited Turkey, Russia, Italy, and North and South America. He was also Consulting Engineer to the Windsor Royal Gas Company.

Mr. Upward preserved freshness and keenness of intellect to the end. Originality of mind, unlimited energy, extreme kindliness of disposition, and absolute straightforwardness in business matters, may be said to have been his chief characteristics. He was very successful in the management of large bodies of men, and had an unusual influence over them, arising no doubt from the fact that he never lost an opportunity of knowing them as individuals and of taking a real interest in them.

Two incidents in the course of Mr. Upward's connection with the Gas Light and Coke Company which are specially interesting on account of the personal risk involved were the gas-holder fire in 1857 and the Wood Street fire in 1860. In both cases it was not merely a matter of superintending; what had to be accomplished was of such a special nature that it needed to be done personally. The gas-holder fire was a very serious matter, on account of the danger to the entire Works. It was occasioned by one of the columns and part of a girder, struck by lightning in the severe storm of August, 1857, falling on the gas-holder itself and causing a large rent in the plates, from which the ignited gas issued in an enormous flame. Mr. Upward succeeded in getting this under by the application of quantities of damped boarding and wet sacking in constantly lessening circles, thus reducing the flame to final extinction.[1] In the Wood Street warehouse fire, which was occasioned by a gas explosion, Mr. Upward personally

[1] An account of this incident is recorded in *The Journal of Gas-Lighting* for the 18th August, 1857.

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effected the escape of the entire staff by forcing a way through the roof. This warehouse had nothing to do with the Company's works, and Mr. Upward was merely called to the scene on account of the gas explosion which preceded the fire.

At various times Mr. Upward conducted a number of tests and experiments on fuel and gas production, and was one of the Associate Jurors (Class XXXI.) of the Exhibition of 1862.

He was elected an Associate of the Institution on the 2nd May, 1843, and was transferred to the class of Members on the 10th May, 1864. At the time of his death, which took place at 1 Mechlin Mansion, Brook Green, on the 29th March, 1902, Mr. Upward was tenth on the list of seniority of the Institution.

FRANCIS GEORGE ALEXANDER, a second son of the late Mr. George Alexander, of Erindale, co. Carlow, was born on the 26th January, 1864, and was educated at Trinity College, Dublin, where he graduated in arts and engineering. After being engaged for twelve months under Mr. Macassey as an Assistant Engineer on the Belfast Waterworks, he spent over two years in South America, where he was employed on the construction of the Northern extension of the Central Uruguay Railway. Returning in 1892 he was for a time in the R. E. Division Office at Cork, and was subsequently engaged in Parliamentary work for the Mourne water scheme for the supply of Belfast until 1895, when he was appointed Resident Engineer on the construction of the pier and jetty at Bangor, co. Down. In 1896 he went to Newcastle, co. Down, where he was in charge of important operations in the Mourne mountains in connection with the Belfast water supply. In 1899 he was appointed R. E. Division Officer at Cork, where he rendered valuable service in the design and construction of rifle ranges and other military work. He was an accomplished and versatile engineer and an admirable draughtsman, and one whose sterling worth was recognized by all with whom he came in contact. Mr. Alexander died on the 17th April, 1902.

He was elected an Associate Member of the Institution on the 1st December, 1896.

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JOHN BARTON, born in 1814, began his engineering career in 1847, when he entered the service of Messrs. Pontifex and Wood, makers of sugar machinery and distilling plant, with which firm the whole of his professional activity was identified. After being engaged for five years in the erection of sugar machinery in the East Indies and in Java, he was placed in charge of the engineering works of the firm in Shoe Lane and at Millwall, in which position he remained until 1882, when he retired from active work. During that period he designed, and was responsible for the erection of numerous sugar factories in Germany, Austria, France, Belgium, and other parts of the world. He also designed and constructed distilleries, breweries, refrigerators and ice-making machinery. Mr. Barton died at his residence, Torwood, Wimbledon Park, on the 4th March, 1902.

He was elected an Associate of the Institution on the 23rd May, 1865, and was subsequently placed in the class of Associate Members.

ARTHUR HOWARD BENHAM, born on the 2nd May, 1865, was educated at University College School, London, and served an apprenticeship from 1883 to 1886 to Messrs. J. and H. Gwynne, of the Hammersmith Ironworks. In June of the latter year he joined the firm of Benham and Sons, of Wigmore Street, London, and from that time was engaged in the manufacture of engines, boilers, and hydraulic machinery. Mr. Benham died, after a long illness, at Northampton, on the 22nd January, 1902.

He was elected an Associate Member of the Institution on the 3rd March, 1891.

JOHN DAVIS, Honorary Colonel of the 3rd (Militia) Battalion of the Queen's Royal West Surrey Regiment, and an Aide-de-Camp to the King, died on the 7th July, 1902, from pneumonia at Till Hill, Tilford, Farnham, the residence of his relative, Mrs. Hawkes, widow of the late General H. P. Hawkes, C.B. The eldest son of Mr. John Griffin Davis, of Clapham, he was born at Rainford, Lancashire, in 1834, and, after serving an apprenticeship at the works of the London and North Western Railway Company at Crewe, was engaged for some years in the office of the late Colonel John Pitt Kennedy, R.E., Consulting Engineer to the

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Bombay, Baroda and Central India Railway Compan subsequently for many years senior partner in t Dewrance and Co., London. In 1863 he married the Mr. Samuel Curtis and widow of Mr. John Dewran Davis was Provincial Grand Master of Surrey Freer interested in archæology, and was the author of hist Regular and Militia Battalions of the Queen's Royal Regiment. He was appointed an A.D.C. by Queen Vi

He was elected an Associate of the Institution on the 1863, and was subsequently placed in the class Members.

WILLIAM HENRY FOX, born in 1844, obtained his engineering training as a pupil of the late Mr. James P had a considerable practice in water and sewerage wor expiration of his pupilage he was engaged for about a Assistant to the late Mr. G. W. Stevenson, and subseq similar capacity to Mr. Parnell, Architect, of Newcas From 1866 to 1868 he acted as Resident Engineer for on the Rochester and Chatham Waterworks and o drainage of Canterbury. He then assisted the late Jacob in the preparation of a scheme of main drain town and district of Bromley, Kent, and was subsequen for five years as Chief Assistant to the late Mr. Jabez numerous gas, water and sewerage works. In 1872 a contributed Papers on Railway Brakes to the Transac Society of Engineers.

Mr. Fox was appointed Engineer and Surveyor to of Barrow-in-Furness in 1878, and held that post for years. During that period he designed and constru important works for the improvement of the town, a may be mentioned sea-embankments, iron and stone large portion of the main drainage of the borough sanitary improvements, and he carried out the constru Harlock storage reservoir and filter beds, and rend service in connection with the Duddon water sch is about to be carried out by Mr. A. H. Strongitharm died at Barrow-in-Furness on the 24th May, 1902.

He was elected an Associate of the Institution on th 1872, and was subsequently placed in the class Members.

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ALFRED REGINALD TOCKE, born on the 19th January, 1867, was educated at the Royal College, Colombo, Ceylon, and at King's College School, London, from which he entered the Applied Sciences Department of King's College. He passed brilliantly through the engineering course of that college, being second in the final examination and obtaining the diploma of an Associate. On leaving King's College, Mr. Tocke was engaged for four years on the construction of the Manchester Ship Canal as an Assistant on the staff of Sir Leader Williams. In 1892 he entered the service of the Public Works Department of Ceylon. He was first posted as District Engineer in charge of flood outlets, and in 1896 he was appointed District Engineer at Badulla, where he succumbed to an attack of typhoid fever on the 15th January, 1902.

Mr. Tocke was elected an Associate Member of the Institution on the 7th March, 1893.

THOMAS BERNARD COLLINSON, Major-General R.E. retired, died at Little Haven, Ealing, on the 1st May, 1902. A son of the Rev. John Collinson, Rector of Gateshead, he was born in 1821, and entered the corps of Royal Engineers in 1838. After being engaged on ordnance survey work in Wales, Ireland, and the North of England, he sailed in 1843 for China, and was employed for several years on a survey of the coast. From there he went to New Zealand to assist in constructing roads in the North Island, and took part in the movements directed to quell the native disturbances in 1847. On his return to England in 1850 he was employed at the Great Exhibition and subsequently at Waltham, until he was placed in command of the Royal Engineers at Aldershot in 1856. In the following year he was sent to the Mediterranean, where he was second in command at Corfu for three years and at Malta for a similar period, with an interval of six years at Chatham as instructor in architecture. In 1869 he was appointed to the command at Dover, where he remained till his retirement from the corps in 1873. After living for a time at Basingstoke he held the post of architect to the Scotch Prisons Commission until he was forced to resign owing to ill health. He then settled in Ealing. General Collinson married in 1856 Katherine, daughter of the Rev. J. Baker, Chancellor of the Diocese of Durham.

He was elected an Associate of the Institution on the 7th May, 1861.

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WALTER MARDON DUCAT, Colonel R.E. retire
Las Palmas, Grand Canary, on the 12th January, 190
1837, he gained the Willock India Cadetship at Kensin
in 1854. On leaving the Military College at Addiscon
gazetted to the H. E. I. C. S. Engineers in June, 185
completed a further course of study at Chatham he
India, and landed in Bombay in May, 1858.

As an Assistant Engineer he was occupied, till Jun
various works in Bombay, Asirghur and Dhulia.
following years till 1886 he held executive charge of p
in different parts of the Bombay Presidency. After
in the Tanna District he was transferred to Bombay,
land reclamations, the lighthouse, docks, and many othe
works were undertaken and completed. During 1871
at Aden, and then for five years his head-quarters were a
There he completed two large bridges over the Panchg
the Town Hall, gardens and Rajaram College; the Kolh
road (48 miles), including the Amba-Ghat road
Kolhapur with the sea at Rutnaghiri; an additio
supply to Kolhapur City; and the preservation of th
Tank. He was one of the officers thanked by Gove
"Meritorious service" during the famine of 1876–77.
till 1885 he was in charge of works at Poona and Kirke
he published books on the "Sewerage of Poona" and on
Supply and Sewerage of Ahmedabad." At the end
services were lent for four months to the Ahmedaba
Municipalities. During 1886 Colonel Ducat held
Superintending Engineer, first of the Central and
Northern Division of the Bombay Presidency, Pu
Department. He finally left India in 1887.

Shortly after the termination of his Indian car
Ducat entered the service of the Local Government B
capacity of Engineering Inspector. Throughout the pe
employment, extending from April, 1888, to Septembe
was recognisd as one of the most valuable members of t
staff. In matters of engineering the wide range of
India was found to have peculiarly fitted him for the
the innumerable problems associated with the attemp
authorities to meet the varied wants of English c
But he had also a remarkable aptitude for the practical
of other branches of science, and hence it came to pass
for example, the subject of a local enquiry was such as

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close examination from the point of view of the chemist or geologist, the conduct of the investigation was entrusted with confidence to Colonel Ducat. Nor were these the only gifts which rendered his service noteworthy. His manner was refined and genial: his tact never failing, while his insight into character was acute and accurate. Thus he was equally in demand and equally successful whether the matter for discussion and report was, in its essence, of scientific or of administrative importance, and when his connection with the Local Government Board was severed by his resignation of the office which he had so worthily filled, the loss the department sustained was universally admitted to be one affecting many varieties of its work.

He was elected an Associate of the Institution on the 1st December, 1868.

WILLIAM FREDERICK FAVIELL,[1] the fourth son of Mr. Mark Faviell, was born at Kirkby Overblow, near Wetherby, Yorkshire, on the 26th July, 1822. His father had for many years been engaged in the construction of canals, bridges and public works as a contractor. The subject of this notice was educated at a private school at Lincoln, and at the age of seventeen was engaged by his brothers to assist them in the construction of part of the Manchester and Leeds Railway near Wakefield and Horbury. In 1840, on the completion of that work, he was employed on the Dearne and Dove Canal; and in 1841 he assisted in superintending some work on the Eastern Counties Railway near Colchester, on which line his brother had a contract. From 1842 to 1846 he assisted his father in some drainage improvements in Lincolnshire, as well as in surveys for new railway undertakings.

In October, 1846, the Directors of the Leeds and Thirsk Railway accepted the tender of Mark Faviell & Son for the construction of about six miles of that line between Harrogate and Ripon, the management and direction of which work rested mainly upon Mr. W. F. Faviell as partner with his father in that contract, which was completed in 1849, and in the same year on the completion of that, his first contract, Mr. Faviell left Yorkshire to reside in Egham, Surrey, having in January, 1847, married the eldest daughter of Mr. John Carr, of Colchester. In 1850 he entered into a contract, in partnership with his brother-in-law,

[1] This notice is chiefly autobiographical.—Sec. Inst. C.E.

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Mr. John Maxfield, for an extension of the Leeds
Railway to Northallerton. When that work was fairl
the latter part of 1850 Mr. Faviell joined Mr. Henry Fo
of Sir John Fowler, Past-President, and sent in a tende
railway contract in Western India, from Bombay to T
tender was accepted by the Great Indian Peninsu
Company. Mr. Fowler left for Bombay in December, 18
collecting materials and assistants for the work Mr. Fav
in February, 1851, to actively prosecute the work, wh
not a long or a heavy contract, was a new and strang
to carry out in that country. Mr. Fowler's health fa
few months' exposure to the climate of India, and co
return to England. The execution of the contract th
entirely upon Mr. Faviell, and was completed to the sa
the Company, the line being opened for traffic on the
1853. That was the first line of railway opened for
in India, and in its construction the first locomotive
in Asia was introduced on the 23rd February, 1852, fo
the line near Bombay. Early in 1854 Mr. Faviell re
his family to England, to recruit his health, which
from exposure to the sun in directing the operati
contract.

In November, 1855, Mr. Faviell again left England
as the Directors of the Great Indian Peninsula R
accepted his tender for the construction of the
Railway Incline, 15 miles in length, and the continu
railway from the top of the incline to Poona, a distance
The works on the Bhor Ghát Incline were of great
and the line into Poona contained a large amount of r
several large viaducts. They were pushed on with g
and nearly 20,000 men were engaged at one time
memorable year of the mutiny, which broke out in
Although Bombay and Western India were not the sce
actual fighting, yet the regulations found necessary by
ment in reference to labour and transport at a great c
a severe check to the operations. The number of
available was much reduced, and the price both of n
labour seriously advanced. The contractor persevere
and in 1858 finished 3 miles of the Bhor Ghát I
the 40 miles on to Poona, opened for traffic from K
Poona in that year. There was still a considerable
work to be done on 12 miles of the lower part o
Ghát Incline, and as labour was now more difficult

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and the cost greater than the contract prices, the contractor made application to the Acting Board of Directors in Bombay for an increase on the rates, which being refused, Mr. Faviell surrendered his contract, being paid for all the work and materials to that date on the contract terms. In the meantime the Board of Directors in England, under the advice of Mr. Robert Stephenson, the Consulting Engineer, had consented to an increase on the contractor's terms; but there being no telegraph to India at that time, the information did not reach Bombay until the day after Mr. Faviell's departure by steamer for England in May, 1859.

Mr. Faviell's health was so much injured by the great strain and anxiety of the previous four years, that the change to England was necessary, and it was not until 1861 that he felt strong enough to make two or three journeys to Spain, for the purpose of taking up some railway works in that country, which, however, he did not succeed in obtaining on satisfactory terms.

At the close of 1862 the Crown Agents for the Colonies accepted, on behalf of the Government of Ceylon, Mr. Faviell's tender for the construction of 73 miles of a very difficult railway in that country, and in February, 1863, he left England with a large staff to carry out that important work. The railway—the first constructed in Ceylon—runs from Colombo to Kandy, and, as many who have travelled upon the line since its completion may have noticed, the country at the foot of the hills between 30 and 50 miles from Colombo, is full of rank vegetation, and malaria so infested the district that many lives were sacrificed, and the progress of the works constantly interrupted before this portion of the railway could be completed. The heavy works and tunnels on the Kadugannawa Incline, of 1 in 45 for 12 miles, also involved much anxiety and responsibility to the contractor. The whole line was completed to Kandy and opened through for traffic in August, 1867, and Mr. Faviell returned to England in the following September, much broken in health by continued attacks of ague and fever, which clung to him for some years.

It was not until the year 1877 that Mr. Faviell entered into a contract with the Government of the Cape of Good Hope for the construction of 120 miles of railway in the Eastern provinces extending to Graaff Reinet, and also in 1879 for a further contract of 54 miles to Cradock. Those works, ably directed by Mr. J. A. Kendrew, who had assisted him in Ceylon, were completed to the satisfaction of the Cape Government in 1881.

During the last twenty years of his life Mr. Faviell was not engaged professionally, and devoted himself to agricultural pursuits

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and to the rearing of stock, in which he took great interest. He died at his residence, Sandhurst, Tunbridge Wells, on the 3rd July, 1902, in his 80th year.

He was elected an Associate of the Institution on the 4th February, 1868.

*** The following deaths have also been made known since the 4th July, 1902:—

Associate Members.

DUFF, WILLIAM AITKEN; *died* 20 March, 1902.

PIERCE, JOSIAH, Jun., M.A. (*Cantab.*) *died* 30 July, 1902.

WEIR, ARTHUR HERRING, *died* 26 July, 1902.

Associate.

ROBINSON, HENRY (of Rinkendorf, Prussia); *died* 14 January, 1902.

Information as to the career and characteristics of the above is solicited in aid of the preparation of Obituary Notices.—SEE INST. C.E., 8 August, 1902.

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Sect. III.

ABSTRACTS OF PAPERS IN SCIENTIFIC TRANSACTIONS AND PERIODICALS.

The Electric Overhead and Underground Railway in Berlin.

Langbein.

(Zeitschrift des Vereines deutscher Ingenieure, 1902, p. 217.)

The Author of this Paper fills over fifty pages of the journal with descriptions and plans of the line, in length about 10 kilometres (6¼ miles) of which about 1 mile is underground, the remainder being carried on viaduct along the central promenade of the streets.

The gauge is 4 feet 8½ inches, and the motive power is continuous electric current, the maximum speed of the trains being 50 kilometres (31¼ miles) per hour. The line has been constructed and is being worked by a company which is allowed the use of the public streets on various conditions, the most important of which is the payment of a minimum of 2 per cent. on the gross takings. The City of Berlin has also reserved the right to purchase the railway any time from thirty years after the date of the signing of documents.

The Author takes up in order: The history of the undertaking, the general scheme, the structural details of the viaducts and tunnels, the permanent way, feeders and working conductors, the power station and machinery, the architectural treatment of the structures—this being a special feature of a portion of the line—the rolling stock and working of the traffic, and finally the carrying out of the work, which was rendered specially difficult on the tunnel portion on account of the high level of the subsoil water.

A special feature of the scheme is the junction triangle where the east and west line joins a portion going north by two fork lines; the three junctions on curves of 4 chains (Gunter's) radius and gradients of 1 in 38 have no diamond crossings, they are all flying junctions. The area of ground in which the three junctions lie is about 2 acres in extent. The viaducts consist mostly of framed girders resting on steel columns. Each alternate span has the columns rigidly connected with the girders, making a five-fold statically indeterminate structure; the intermediate girders rest freely on the projecting ends of these. The æsthetical treatment

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of the viaducts and high-level stations received very great attention and constitutes an advancement on previous practice.

The tunnels are single; that is, they contain both the up and the down line, the span of the roof is in two portions, however being divided by a row of columns in the 6-foot space. The roof of the tunnel consists of rolled beams and concrete arching, the bottom and side walls of concrete with a thick layer of asphalt to keep out the subsoil water.

The change from viaduct to tunnel is made by a portion of the line on a gradient of 1 in 32. The stations are of the simplest possible character, having no waiting-rooms. The trains consist of three coaches, a motor car at each end, and an ordinary carriage in the centre, the seating capacity of the train being 122 passengers.

Further extensions of the underground portion of the line are in progress, others are contemplated.

J. G.

The Berne Neuenberg Direct Railway. ALBIN-BEYELER.

(Schweizerische Bauzeitung, 1902, pp. 1–18. Map and 12 Figs.)

This line was opened upon the 1st July, 1901, and is of great importance for Swiss railway traffic. The project was first brought forward in 1852, but only seriously considered in 1874, and the Author gives a short account of the difficulties in obtaining the necessary power from the Government. The estimated cost was about £526,320, and after various projects had been considered it was decided that the total length must not exceed 26·66 miles as compared with the existing line 39·06 miles long, and the ruling gradient must not exceed 1 in 50. The line is of normal gauge, and the minimum radius of curves 327 yards. About 65 per cent. of the entire length is level or on gradients not exceeding 1 in 250, and over 70 per cent. of the length is straight.

The actual costs up to January 1901, including about 99 per cent. of the earthworks but exclusive of certain station buildings, was £468,000. The actual cost will therefore be considerably below the original estimate.

Some of the principal engineering works upon the line are the following. The Saane viaduct, which is 436 yards long and has a maximum height of 103·3 feet, with 27 masonry arches of 32·8 feet span and a centre opening 201·7 feet wide which crosses over the Saane. Spanned by a lattice girder bridge, the viaduct is illustrated and described in detail. It was built by Wartmann and Vallette of Brugg; at the test the bridge was loaded with 302 tons and the maximum deflection was 1·10 inch compared with the calculated deflection of 1·18 inch.

The Zihl bridge, the second important construction, was built by

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Theodor Bell and Co., of Kriens. It has a span between supports of 249·3 feet and a width of 16·4 feet between centres of the side girders; the roadway is supported upon the bottom booms and the upper booms are of half parabolic form. The bracing consists of vertical struts and diagonal tension bars. The height of the girders at the centre is 33·5 feet. This structure is also illustrated and described in detail.

There are also several tunnels; that at Rosshäuser is 1,201 yards long, and small air shafts were constructed at intervals of 109 yards. The tunnel at Faverwald is 469 yards long, and as it passes through gravel and earth is constructed with thicker masonry. Sections are given of both tunnels.

E. R. D.

Concrete Bridge upon the Gürbethal Railway, Switzerland.

R. Moser.

(Schweizerische Bauzeitung, 1901, p. 257. 3 Figs.)

On the 14th August, 1901, the central section of the Gürbethal railway was opened. This line will eventually be extended to Berne in one direction and Thun in the other. At one point the line crosses the road from Berne to Köniz, and the bridge has been built of concrete. It consists of a single span of 76·75 feet and rise of 19·6 feet, and upon each of the haunches are three small arches to carry the roadway. The arch is 2·62 feet thick and 15·84 feet wide at the crown, and 4·92 feet thick and 19·7 feet wide at the springing.

With a total static load upon one side of the bridge amounting to 307·5 lbs. per square foot, the pressure upon the foundations is 1,224 lbs. per square foot for the upper edge and 9,419 lbs. for the lower edge, while the greatest tension at the crown is 187·7 lbs., at the haunches 132·2 lbs., and at the weakest point 220·4 lbs. per square inch. For foundations and buttresses concrete consisting of 1 part Portland cement, 3 parts sand and 6 gravel was used, but for the arch the proportions were 1 : 2·5 : 5. The concrete used amounted to 732 cubic yards. The structure was loaded with locomotives, giving a load of 14·2 tons per axle, and the maximum deflection at the crown was only 0·0276 inch.

The total cost of the bridge was only £610, while an iron bridge with concrete abutments would have cost £1,040.

E. R. D.

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Signalling on the High-Level and Underground Railway in Berlin. LANGBEIN.

(Zeitschrift des Vereines deutscher Ingenieure, 1902, p. 305.)

In the meantime, with a 5-minutes' service of trains, the beginning and end of each block section coincides with a station. Almost all the stations have starting signals only, no distant or warning signals being employed, except at the junction triangle. After a train leaves a station the starting signal is put to danger and the signals "train entering section" and "line clear" are sent to the stations in advance and in the rear respectively. Until this "line clear" signal has been given, the starting signal of the rear station remains locked, and the sending of "line clear" releases the starting signal. A rail contact is arranged about a train length in advance of the starting signal, and until this is actuated by the train the signalman is unable to lower the block for another train to follow. The starting signals are actuated by hand. At the junction triangle there is a signal-box from which the points and signals for the three junctions are worked by electric power. Each pair of points is provided with a motor, by the motion of which the points are reversed and locked. Simultaneously also the signals are set to correspond. There are three wires between each motor and the cabin.

J. G.

Electrically-Driven Railway Turn-Tables. E. BLOCK.

(Annalen für Gewerbe und Bauwesen, 1 May, 1902, p. 184.)

Reference is made to the general system of moving turn-tables with hand-levers, which involves a heavy expenditure of labour on the part of the workpeople, and not infrequently causes injuries to them by the excessive strain. In some cases hand-winding-gear has been introduced for this purpose with advantage, but this is a very slow process. To obviate these drawbacks, steam- and gas-engines have been employed at considerably increased cost, and these in turn gave way to electro-motors, by which means the operation of turning an engine could be effected in $1\frac{1}{2}$ minute. Attention is called to a new form of motor, which is mounted on a trolley and works direct by toothed gear on to the driving wheel, which runs round in the pit on the same rail as the bearing wheels of the turn-table. The trolley has a strong iron frame, on which is mounted a 10-HP. reversible-current motor, which acts on a broad driving-wheel by a double train of toothed wheels. The current is conveyed underground by means of a cable to two copper rings fixed on the centre bearing of the turn-table and thence to the trolley. Details are given of the method of driving. When empty a complete revolution of the turn-table

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can be effected in 30 seconds. Loaded with a ten-wheeled locomotive and tender, weighing altogether 100 tons, a full revolution can be completed in 45 seconds. The total cost under the given conditions of the amount of current needed, with fuel at 20*s*. per ton, being $\frac{1}{4}d$. Figures are given of the apportionment of the load on a turn-table of standard size for the Prussian State Railways, which is 52·74 feet in diameter and weighs about 24·6 tons, and a calculation of the work to be done leads the Author to the conclusion that 4·7 HP. is all that is required to move a live load of 109 tons at the above-mentioned speed.

G. R. R.

Snow Fences. E. Schubert.

(Organ für die Fortschritte des Eisenbahnwesens, 1902, p. 1.)

This paper deals with the form and magnitude of snowdrifts at fences of various kinds, actual trials being made with fences specially set up in line with one another and allowed to stand through two or three snowstorms. The effect of the different forms was judged by the shape and area of a cross-section of the drift at right angles to the fence. The snow was cleared away to one side of the section for the purpose of measurement. Photographs were also taken, sixteen of these being reproduced in the Paper.

The fences are supposed to be at such a distance from the railway that the wind, after having its velocity reduced at the fence and allowing the snow to settle, again attains a velocity over the line, sufficient to sweep the snow before it. Upright or slightly-inclined close fences collect considerable quantities of snow on the windward side, and less on the lee side. If the wind is blowing at the rate of from 26 feet to 50 feet per second, the ground at from 16 feet to 50 feet on the lee side of such a fence will be swept clear. If the wind is blowing stronger, say about 82 feet per second, the ground previously left bare becomes covered. An actual case is mentioned by the Author, in which an inclined fence about 33 feet from the top of a cutting kept the line clear for some time until, a more violent storm coming on, the line was drifted over. Fences consisting of posts with boarding fixed horizontally in 6-inch widths with 2-inch spaces were also tried, and they were found not very different in their action from solid board fences; there was generally a depression or ditch formed by the drift in front and behind these fences.

Among the other kinds experimented with, woven-wire fences were the most important. Indeed, a wire fence with 0·35 inch mesh was the most effective screen of all the fences put up; it gathered twice as much snow as a close fence of the same height

J. G.

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On Compressed-Air and Electric Boring Mac
Tunnels. T. GILLER.

(Oesterreichische Zeitschrift für Berg und Hüttenwesen, August,

This is a review of the different methods in use time for rock drilling, and more particularly in la railway tunnels. Electric boring-machines, alth tageous as regards supply and economic in expendit are costly and complicated, taking up considerabl underground than compressed-air drills of the same the case of the rotatory percussive electric drill, wh by a flexible shaft and independent motor, there a the transmission shaft, motor-box and supporting pilla 330 separate parts as against 40 or 50 in an air drill; the auxiliary level at Raibl, where two of these m use, there were in nine months 186 breakages, includ working springs and 142 of the crank axles, or nearly daily for every working day; while, in a simil compressed air-drills worked night and day contin same time without any stoppage for repairs. A complicated form of the same machine, with only since been constructed, but has not yet been brou The solenoid electric borer, although handier than form, has the disadvantage of requiring supply-c section, owing to the low voltage, 220 volts; so t scarcely be usefully applied at a greater distan metres from the generator, and the rapid diminution the heating of the coils, is such that the machines mu for cooling at intervals of $\frac{1}{2}$ to $\frac{3}{4}$ of an hour. The to compressed air is in the large expenditure of po Thus the electric rotating machine requires $1\frac{1}{2}$ solenoid machine 4 to 5 HP. and the compresse 5 to 11 HP., according to the power of the compressor figure corresponds to the most powerful tunnell which far exceed any electric one in capacity. The tageous arrangement, the Author considers, is to be combined system of Messrs. Meyer, of Mulheim. In thi air drills are used, which are supplied from a portab driven by an electric-motor mounted upon a railway it can be brought as close as necessary to the wor driving current being derived from a generator at a this way the loss of pressure due to long lines avoided. A quick running form of compressor is ad the dimensions are considerably reduced, bringing a within the dimensions of an ordinary mine wago 4 feet high and 3 feet broad. When running at 2 per minute a pressure of 5 to 6 atmospheres is o system has been introduced for driving levels at

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Wilhelm Mine, Friedenshütte, in Upper Silesia, where levels 6½ feet square in coal shale are driven at the rate of 7½ feet per day, by its use.

H. B.

The Plant in use at the North End of the Simplon Tunnel.

S. PESTALOZZI.

(Schweizerische Bauzeitung, 1902, p. 87. Figs.)

At the north end of the Simplon Tunnel the plant may be divided into that fixed outside the tunnel, that fixed inside it, and the rolling stock, &c.

The pumping apparatus occupies the chief place, and delivers high-pressure water to the rock-drills, fans, &c. Upon a horizontal main shaft are arranged four Pelton wheels, each of which drives two pairs of pressure pumps. Each of two turbines develops 250 B.HP., and the pumps deliver the water at a pressure of 1,800 lbs. per square inch. One turbine of 600 B.HP. drives a larger pair of pumps. Two pressure accumulators are used, and these are adjusted to any desired pressure. These three turbines and six pairs of pumps are sufficient for the rock-drills and the ventilating apparatus.

Near the pumping station is a reserve steam plant consisting of three semi-portable engines, one of 60 N.HP. and two of 80 N.HP. each.

A fourth turbine of 600 B.HP. drives the air compressors, and also serves as a reserve source of power. The air is compressed to 1,500 lbs. per square inch in two stages, and is used in the locomotives working in the tunnel near the face. Storage reservoirs of Mannesmann tubes are used, and these are kept supplied from pipe lines.

The compressors are of the Burckhardt and the Ingersoll-Sergeant type; the water-pumps are also employed to supply the cooling water. It is considered by geologists that a temperature of 107° F. will be found in the tunnel workings, and it is intended therefore to reduce the temperature by passing cold water through cooling pipes. This is effected by means of two groups of Sulzer high-pressure centrifugal pumps driven by turbines, each group requiring 300 B.HP. The pipes are carefully insulated until they reach the working face, so as to obtain the highest possible efficiency.

Adjoining the pump-room are the repairing shops and also the dynamo-room. In the latter are installed one 25-HP. and one 100-HP. machine for lighting, and also a 30-HP. direct-current machine driven by belting from a shaft actuated by two turbines. On the south side there is a 100-HP. lighting machine driven direct from a turbine and developing 120 volts, and also a 25-HP machine giving 250 volts.

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There is also a special building provided wit
accommodation for 1,500 men, and fitted with douc
and an ingenious arrangement for drying the wet
in the tunnel.

The Pennsylvania-Avenue Subway and Tunnel,

GEORGE S. WEBSTER and SAMUEL TOBIAS WA

(American Society of Civil Engineers, March, 1902, pp. 19

The object of this work was to abolish the le
hitherto necessitated by the Philadelphia and Rea
running along the Pennsylvania Avenue on the
Along this route the railway has been lowered into
tunnel at a depth leaving a sufficient headway
crossing streets. During the progress of the work
traffic was temporarily diverted into a neighbouring
lowering involved the construction of inclined s
various works and warehouses situated along the
railway, with which they had previously been con
level. Rack-rail gradients of 10 and 12 per cent., fo
had been worked out, were ultimately abandoned, i
advantages they offered; and all connections w
5 per cent. adhesion gradients. The methods of und
walls of buildings situated alongside the railway are
illustrated. The detailed modes of excavating and
left to the ingenuity of the contractor; some of these
and illustrated. Where it was not expedient to under
their fronts were removed and reconstructed. Re
were all constructed of rubble masonry, under general
which are given. Wherever possible their face ha
$\frac{1}{2}$ inch per foot. Where a retaining wall was in line
of a building, its face was vertical. Standard dimens
are shown for retaining walls with and without
summary is given of the cost for underpinning, for
buildings, and for retaining walls. The tunnel, orig
to be 52 feet wide and 2,913 feet long, was in
artificially ventilated by two exhausting fans; but it
shortened to 2,710 feet, and ventilated through roof
the street above. Extracts are given from the spe
the steel-work required in the construction of the
and for the means of thoroughly protecting every
from the fumes of the locomotives. The main girder
openings were plastered with two coats of cement mo
equally of cement and sand; and their under side
with a ceiling of terra-cotta fire-proofing material. T
of the tunnel was begun on 8 March 1897, and fi
December 1898. The properties are described of the

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stone approved for retaining walls and for bridge abutments; and a table is given of twenty-seven elaborate tests, which show an average crushing strength per square inch ranging from 6,426 to 17,274 lbs. when placed on bed, and from 4,463 to 13,984 lbs. when placed on edge. Tables are also given of the road bridges crossing the subway, of the loads for which they were calculated, and of the tensile tests and chemical composition of the basic open-hearth steel used in their construction.

Other sections of the Paper deal at greater or less length with the details of drainage, railings for bridges and for retaining walls, painting, casing of metal-work with wood sheathing, alterations of water and gas mains, permanent way, interlocking switches and signals, telegraph service, coaling and water supply for locomotives, goods warehouses, engine house and repairing shop, 50-ton electric crane, and various other matters, as well as prices and financial summary. Eighteen photographs illustrate different portions of the work; besides which there are numerous small-scale figured drawings, and a general plan of the route.

There are four lines of rails in the tunnel and subway, and in some places six in the latter. Preliminary operations were commenced in 1894, and the main construction work in 1896; a special passenger train ran through on 1 July 1899, the regular traffic began on 25 September of the same year, and the work was practically completed by November 1900.

A. B.

Anchylostomiasis, a Parasite affecting Tunnel Workers.

L. JEHLE.

(Zeitschrift des Oesterreichischen Ingenieur und Architekten-Vereines, 1902, p. 542.)

The tunnel worm, Anchylostoma duodenale, is a nematode parasite to which labourers engaged in tunnelling are particularly liable. It produces anæmia (chlorosis), and may even lead to fatal results. One of the most recent instances of an epidemic of this parasite occurred during the construction of the St. Gothard tunnel, and resulted in several hundred men being incapacitated. Infection is communicated by the faeces, the eggs discharged from the body therewith hatching out in water to encysted larvae, which develop completely on regaining access to the body *via* the drinking water.

To minimize infection the Hungarian Ministry of Agriculture and Mining has issued instructions that all labourers engaged in tunnel-work (especially those from other districts) must be medically examined for anchylostomiasis; and in addition, the following prophylactic measures should be adopted: compulsory use of special earth-closets made of iron drums and fitted with tight lids, the drums to be removed into the open air daily, and the contents buried after being treated with quick lime and

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vitriol. Peat is found useful for strewing in the drums. Great care should be taken to provide a supply of uninfected drinking water, stored in clean vessels and away from liability to contamination. The addition of about 1 part per 1,000 of pure citric acid to the water increases its thirst-allaying properties, and is also injurious to the parasites. All timberings and wooden walls should be frequently washed over with lime and vitriol; the men should be discouraged from taking their meals in the tunnel, and should wash thoroughly in clean running water on leaving work; they should also change their working clothes, and these should be cleaned at the works before resumption.

Similar regulations proved useful in the case of the Simplon tunnel; and their adoption at the Arlberg tunnel enabled the working staff to be kept free from infection, although many infected men from the Gothard tunnel were employed.

C. S.

Rebuilding of the middle Rhine Bridge at Basel.

(Schweizerische Bauzeitung, 1902, p. 30. 1 Plate.)

In January last, the competition designs for the rebuilding of an existing bridge over the Rhine at Basel were publicly exhibited. It was the most important competition for a bridge ever held in Switzerland. Twenty-eight designs were sent in, while at the Berne competion for the Kornhaus bridge in 1895, only 5; for the Lorraine bridge in 1897, only 16, and for the three bridges over the Florithal in Lausanne in 1898, only 18 designs were received.

The subjects of the earlier competitions were, however, more difficult, which may have diminished the number of competitors; in the latter case æsthetic considerations were of great importance. Public opinion in Berne favoured hard stone as the material of construction; the old bridge had lasted hundreds of years, and it was thought that the new bridge should be designed to last as long. Fifteen of the designs were entirely of stone and thirteen of stone and iron combined. The first premium was gained by a design illustrated in the original and sent in by Albert Buss and Company, engineers, J. Rosshändler and J. Mast, of Basel, and architects, Prof. F. v. Thiersch, of Munich, and E. Faesch, of Basel.

It has six arches varying in span from 80 feet at each side to 92 feet next the centre; the piers also increase in height towards the centre, and the curves of the roadway gives gradients of 2½ per cent. rise. The left abutment consists of two parts, the river retaining wall and the abutment of the old bridge, which is founded upon a solid bed of clay, which also extends higher up. The right abutment is constructed upon groups of piles. The design is of simple form, suitable for the granite which it is proposed to use. The perforated balustrading will be of hard sandstone. It is

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proposed to sink the piers by means of iron caissons, and the lighting is provided by means of arc lamps. Details of the estimated cost are not supplied, but the total is stated as £107,136, and in a subsequent number of the journal descriptive details are given of the design which was awarded the second premium.

E. R. D.

Bridge over the Rhine at Basel. CARL BERNHARD.

(Zeitschrift des Vereines deutscher Ingenieure, 1902, p. 568.)

The first prize[1] was awarded to a design showing a series of stone arches of about 70 feet span, the decision of the judges reading that a bridge built entirely of stone was preferred, as it would offer a contrast to the iron bridges on either side of it, and would introduce a new element into the general view.

The second prize was gained with a design which, in the Author's opinion, would have constituted an ideal solution of the problem, and satisfied all desires for contrast with the existing structures. This scheme is for a two-span continuous girder-bridge, there being two main girders with cross girders resting on the bottom flanges. The bottom flange is straight from shore to shore, while the top flange rises in a gentle curve from the shore ends towards the central pier, which forms a tower of massive appearance. The spans are 96 metres (315 feet) each, the depth of the main girders at the shore end 6 metres (19·7 feet) and at the central pier 15·5 metres (50·8 feet). The Author would have preferred the top flange to have shown a sharper curve upwards at the pier, so as to have more the form of an ellipse. The web-bracing consists of a single system of verticals and diagonals. The combined width of carriage and footways is 18·1 metres (59·3 feet). The cross girders are 7·25 metres (23·8 feet) apart, corresponding with the verticals of the main girder. The total load at one apex of each main girder is about 80 tons, made up of 31 tons external dead load, 17 tons weight of girder, and 32 tons live load. (This is equivalent to a total load of 3·36 tons per foot run, and a load of girder of 0·71 ton per foot run, or about 2·2 cwts. per square yard of area supported.) The load of traffic allowed for was 450 kilograms per square metre (92 lbs. per square foot). The maximum stress in the main girders was calculated at 0·94 ton per square centimetre (6 tons per square inch). The total estimated cost was about £20 per square yard of bridge, or £135 per foot run, about 25 per cent. less than the estimated cost of the first prize design for six arches in granite. The Paper contains general views and plans of the site, sketches of the central tower, and details of the ironwork. J. G.

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[1] *Ante*, p. 476.

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Bridge over the Neckar at Mannheim. CARL BERNHARD.

(Zeitschrift des Vereines deutscher Ingenieure, 1902, p. 253.)

In addition to the designs to which premiums were granted, there were other six schemes proposed, and these the Author considers in this Paper. Some of them were recommended by the judges for purchase by the City of Mannheim, and one such was for a continuous girder bridge of three spans, a centre one of about 400 feet, and two side spans about 200 feet each. The top flange is on a curve having the appearance of suspension chains, and the bottom flange has a slight curvature upwards. The roadway is at the level of the highest part of the bottom flange and the bracing between the top and bottom flanges is N-shaped. The Author considers the appearance of the long bracing bars at different angles somewhat disturbing, and prefers another design by the same competitors, which has the same appearance so far as the flanges are concerned. The top flange in this case forms, however, in reality part of a suspension bridge. The inclined bracing bars above the roadway are omitted, and the bridge is rendered stiff by a continuous girder which does not appear above the parapet. In this design the main towers on each side of the centre span are entirely of iron, and the Author considers this treatment of the piers more advisable than that adopted in another practically identical design, with the exception that the main towers are encased in a masonry structure which looks statically impossible, and in the Author's opinion produces a deplorable effect. The same design, however, has several excellent points, particularly with regard to the treatment of the stiffening girder, for which descriptions and drawings are given.

One design was for a bridge in three spans which, so far as the dead load was concerned, formed a cantilever bridge, and was statically determinate, while for the live load it was a continuous girder twice statically indeterminate.

A masonry arch bridge of three spans was also proposed, the arches being three-hinged and the roadway carried from the arch ring by spandril-piers.

The scheme that has now been decided upon to be carried out is the design for which the second prize was granted.[1]

J. G.

Haupt's Reaction Breakwater.

(Journal of the Franklin Institute, vol. cliv., pt. 1, p. 33.)

This is the report of an expert committee upon the merits of the invention of Prof. Lewis M. Haupt, which consists of a method and means of application whereby channels opening in tidal waters

[1] Minutes of Proceedings Inst. C.E., vol. cxlvii. p. 445.

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may be made practically navigable for vessels of deep draught, at the same time enabling such channels to be kept at the required depth by the operation of natural forces alone and without continued dredging. In the main, the inventor's work consists of an investigation of the natural laws controlling the formation of harbour-bars, sandspits, and other physical features which are concerned with the deposition of littoral drift on alluvial coasts, and a determination of the data relating to these subjects. On various occasions, to which attention is herein directed, the inventor's views have been exhaustively discussed and his theories have been practically tested, notably at Aransas Pass, Texas, where a single jetty, constructed in the form of a compound and reversed curve, has been placed to windward of the navigable channel, and generally in line with the natural trend of the currents. An open space left between the shore and the head of the jetty admits the flood-tide freely, and this opening changes the condition between the ebb and flow movements in such a manner as to cause a larger volume of the ebb currents to pass over a contracted section of the bar, by which means a scour is induced, tending to create a natural channel. At Aransas Pass the depth of the water over the bar has been in this way materially and progressively increased by the employment of natural forces alone. The committee sum up the general principles laid down by the inventor, and the conditions to be fulfilled, in a series of ten conclusions. In recognition of the scientific research, and the practical efforts which have culminated in the invention and demonstration of the "Reaction Breakwater," and of the economies to commerce resulting therefrom, the Franklin Institute has bestowed its highest award, the Elliott Cresson medal, upon the inventor.

G. R. R.

Experiments with Model Groynes for River Engineering.

C. KRISCHAN.

(Zeitschrift des Oesterreichischen Ingenieur und Architekten-Vereines, 1902, p. 469.)

To ascertain the effect of the shape of subaqueous structures on the current of rivers, the Author experimented with various patterns of model groynes, set up on the tailshute of an overflow weir. The most favourable results were obtained by a groyne, the crown line of which takes the form of an unbroken concave curve, the sectional profile being convex at the upper surface and concave on each side. With this form all shock and piling up of the water against the obstacle are avoided, the threads of water remaining unbroken even at the highest part of the groyne, and the main direction of flow suffering no interruption; whereas in groynes with a broken crown line and flat lateral surfaces a

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considerable deviation of the current is produced at each change of direction of this line, and the water is stanked up, with formation of vortices at the higher parts.

The Paper is illustrated with photos and diagrams.

C. S.

The Protection of Dykes. H. Bücking.

(Deutsche Bauzeitung, 1902, p. 267.)

To protect dykes enclosing stagnant or slow-running water from the denuding effects of wave action, especially in the winter season, when the herbage on the grassy slopes is scanty, it has been proposed to employ jute cloth, fastened down with wire cramps or sand bags. This method, however, is attended with the drawback that the growth of the grass is retarded, the consequence being that the protective covering has to be again resorted to early in the autumn, and the condition of the dyke gets from bad to worse. A more effectual protection is afforded by a means devised by the Author, namely, a series of floating booms attached to stays pivoted on supports fixed on the dyke slope. In this manner the force of the wave is broken, and a space of smooth water is provided next the bank, so that the growth of the grass is unimpeded. Where there is any current in the water the uppermost boom of the series must be anchored up-stream; and diagonal ties may be provided from the stay supports to the connections of the next lower pair of booms. The thickness of the booms depends on the strength of the waves, an average of 12 inches to 16 inches being sufficient for the lower course of rivers. As cheap timber may be used, or comparatively thin poles lapped round with brushwood, the expense of this method will not be greater than others; and it has already been proved efficacious in Germany.

C. S.

The Königsberg Ship-Canal.

(Archiv für Post und Telegraphie, 1902, p. 97. 1 plan.)

The official opening of the ship-canal between Königsberg (Prussia) and its harbour, Pillau, took place upon the 15th November, 1901. The work has been of an exceptional kind, as the canal runs through a land-locked lagoon known as the Frisches Haff (Frisian Gulf). Königsberg is situated upon the River Pregel, about 5 miles from the point where the river discharges into the Haff, and the latter is separated from the Baltic by a narrow strip of land known as the Frische Nehrung, through which an opening has been cut at Pillau, 25 miles west of Königsberg. Competition with the Russian ports of Libau and Riga could only be successful

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if aided by a sea-canal. The proposal was first made in the Eighteenth Century, but at that time small sailing vessels only were used, and a depth of 8·2 feet to 9·2 feet sufficed in the water-way. The breakage of the Vistula dams in 1855 caused an immense volume of water to pass along the water-way and scoured it to a depth of 23 feet; but in spite of care it had silted up so much that in 1873 it was only 10·8 feet deep. It was necessary to partly discharge the cargoes into lighters at Pillau, and this caused an outlay of £22,500 per annum. In 1878 a competition was opened for designs of a water-way, with prizes of £500 and £250. The first prize was gained by the design of the harbour-works inspector, Mr. Natus, at Pillau. The German Board of Works suggested an alteration in position of the water-way, and a diminution of the width from 247 feet to 98·5 feet. In 1889 the town of Königsberg agreed to guarantee an annual payment of £6,500, and the State agreed to expend a capital sum of £365,000. In 1890 work began, but it was found desirable to build the retaining walls stronger, and to increase the depth of the water-way to 21·3 feet instead of 16·4 feet, so that the outlay was increased to £615,000. The finished canal has a length of 20·5 miles and a depth of 21·3 feet at mean tides; the water-way is as a rule 98·5 feet wide, but at bends 131 feet, and at the Fischhausener Wick 246 feet. There are also two passing-places. The sides of the canal, where founded upon a sandy bottom, have a batter of 1 in 2·5, but upon a mud bottom a batter of 1 in 5. The sides are low, only rising 2·62 feet above mean water-level. These banks are protected above water-level by a growth of rushes and weeds.

E. R. D.

The Projected Danube-Moldau-Elbe Canal.

RUDOLPH RITTER v. GUNESCH.

(Zeitschrift des österreichischen Ingenieur- und Architekten-Vereines, vol. liv., p. 377.)

The Author, who was charged with superintending the drawing up of the estimates and plans of the two systems submitted to the Canal Committee, describes the projects in detail, and illustrates the Paper with two maps and the same number of profile sketches showing the course of the canal.

The route selected runs from Korneuberg, near Vienna, to Budweis, a distance of 136 miles (219 kilometres); and to carry the canal over the intervening range would require, in the one scheme, the construction of fifty-three locks, each having a lift of 32·8 feet (10 metres), whilst the alternative project would entail the provision of fifteen locks and four boat-lifts on the Shoenbach, or inclined plane, system. It is calculated that the natural rainfall of the region would afford a sufficient supply of water to keep the canal filled, by gravitation, from reservoirs to be constructed in the hills.

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From a comparison of the two projects, the Author concludes that, whilst the prime cost of the canal with locks would be less by 15 million kronen (shillings) than the boat-lift canal, and the annual upkeep would also be smaller, the difference would be about neutralized by the lower traffic expenses of the latter system. At the same time with the lifts there would be a saving of 20 per cent., 40 per cent., and 56 per cent. in the consumption of water at the upper levels of the canal, and the time occupied in transit would be about 25 per cent. less than in the lock canal. On the other hand, the supporters of the lock system point out that the practical working of the Schoenbach lift has yet to be proved, and that this could only be demonstrated by the construction of an actual lift, involving a delay of about 5 years.

C. S.

The Traffic in the Kaiser Wilhelm Canal.

(Archiv für Post und Telegraphie, 1901, p. 651.)

The Chairman of the German Nautical Association, Mr. Sartori, has tabulated a statement of the traffic in the Kaiser Wilhelm Canal for the years 1896 to 1900, and the Tables contain the following figures—

In 1896, the total traffic consisted of 20,068 vessels with a tonnage of 1,751,065 tons, while, in 1900, the similar totals were respectively 29,571 and 4,292,258.

In 1896, vessels to the number of 7,274 passed right through, while 12,794 were engaged in local commerce.

The through traffic in the year 1900 consisted of 32·2 per cent. commerce between Elbe harbours and the Baltic; 24·89 per cent. between the remaining German harbours on the North Sea and the Baltic; and 42·91 per cent. between North Sea harbours not belonging to Germany, and also between other foreign harbours and the Baltic. The chief increase has, therefore, been in the amount of foreign commerce passing through the Canal. In one day the maximum number of ships passing through was 118, with a tonnage of 20,649 tons.

E. R. D.

The Tentschert-Czischek Water Economizer for Canal Locks.

L. CZISCHEK.

(Zeitschrift des Oesterreichischen Ingenieur- und Architekten-Vereines, vol. liv., p. 577.)

The economizer consists of a large storage chamber, communicating with the lock, or preferably with two locks, and containing a displacer, by the movement of which, water is forced from one side of the chamber into the empty lock (containing the barge to

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be raised), whilst the water from the full lock (containing the barge to be lowered) is allowed to flow into the vacant space left in the rear of the moving displacer. The latter apparatus fills the entire length of the storage chamber (which is of the same length as the lock or locks), and in section resembles a lemon, *i.e.*, a square with two opposite corners rounded off into quadrants, leaving the two alternate ends rectangular. By means of teeth on the under quadrant, engaging in racks on the chamber floor, the displacer can be rolled over from one side of the chamber to the other; and, in order to facilitate this movement, the interior of the displacer is divided into three compartments, two in the shape of a widened U, adjacent to the quadrants, and a third, occupying both the angular corners and the rest of the central space. The compartment next the upper quadrant is entirely filled with water, the middle compartment partly so, whilst the under one is empty. For a lift of 5 metres (16½ feet), the displacer measures 12 metres (39·3 feet) at the greater diagonal. The time occupied in turning the displacer from one side of the chamber to the other is estimated at 3 minutes, so that the displacement of the water in the locks will be effected without shock. The force required to move the displacer is calculated to be about 10 per cent. of the total weight raised, so that for a lock 78 metres (256 feet) long, the total force required would not exceed 42 HP. This would be applied to a set of winches acting on five steel wire cables attached to different points on the surface of the displacer and passing over pulleys overhead. The total loss of water by leakage past the ends, and under the bottom of the displacer, is estimated to be about 5½ per cent.; but this can be reduced by packing the ends with leather washers or flexible rings (also to allow of longitudinal expansion, averaging 1½ inch), and by making the chamber floor as level as possible. Provision is made for insuring rigidity in the displacer by means of internal lattice girders and partition walls. The expense of renewing loss by leakage may be reduced by charging the storage chamber with more water than is actually required to fill the locks, so that the displacer will not need to be tipped fully over until the leakage renders this necessary. The storage chamber may be situated between the two locks, or, wholly or partly, at the side, according to local conditions.

The Paper is illustrated by plates and diagrams.

C. S.

The Transmission of Heat in Evaporation. Dr. H. Claassen.

(Zeitschrift des Vereines deutscher Ingenieure, 1902, p. 418.)

The transmission of heat which takes place from saturated water-vapour on one side of a plate to boiling water on the other side, is in some respects a simple process, but, in the Author's

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opinion, one which is not properly understood. Some authorities have held the opinion that the coefficient of transmission of heat is uninfluenced either by the temperature of the steam, or the difference between the temperature of the steam and that of the boiling liquid. The Author holds that experiments made by him entirely disprove this. Before passing on to his experiments, he points out that the layer of condensed water on the steam side of the plate, as also the bubbles of steam on the water side, must play a considerable part in the transmission of heat, and he discusses the effect of the variation of the temperatures of the steam, condensed water, that of the two sides of the plate, and of the evaporated water, at considerable length.

The experiments were carried out with great care on a small scale, and afterwards with full-size apparatus. The arrangement on the small scale consisted of a cylindrical iron vessel 480 millimetres (19 inches) in diameter, and 1,150 millimetres (45·3 inches) in height. The water to be evaporated was put in this vessel, the evaporating steam being caused to circulate through a copper-worm laid in the bottom. Water-gauges, pressure-gauges and thermometers were fitted to the steam-pipes, etc. The whole apparatus was set on the scale-pan of a balance. The radiation of heat through the walls of the cylinder was carefully determined, with the steam shut off from the worm. The results of the experiments are contained in tabular form in the Paper, and show that the transmission of heat increases with the difference between the temperature of the evaporating steam and that of the evaporated steam. The Author finds an explanation of this in the more energetic circulation of the water through the increase in the number of steam-bubbles, this increase being occasioned by the greater difference in the two temperatures. With the temperature difference remaining the same, but both temperatures higher, the transmission of heat is also greater. The greater the height of the liquid above the worm the less the evaporation.

Solutions of salt behaved almost like pure water, while sugar solutions diminished the coefficient of transmission of heat. Tables of the results with the larger apparatus are also given in the Paper.

J. G.

Air-Condenser for Steam-Engines of 4,500 *HP.*

FRÉDÉRIC FOUCHÉ.

(Mémoires de la Société des Ingénieurs Civils de France, 1901, pp. 651–61.)

For the Kalgoorlie Electric Power and Lighting Corporation in Western Australia three vertical compound engines are being erected by Messrs. White and Co., which will together furnish 4,500 HP., and consume 48,000 lbs. of steam per hour. Owing to

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the dearth and dearness of water in the locality, the whole of the steam will be condensed without any loss in an air-condenser constructed by the Author, comprising twenty-seven propeller ventilators of 2·2 metres (7¼ feet) diameter with helical blades, running at only 300 revolutions per minute, which will blow 2 million cubic metres (70 million cubic feet) of air per hour over the condensing surfaces. These surfaces are composed of corrugated steel sheets 1 millimetre ($\frac{1}{25}$th of an inch) thick, united in pairs by interlocking their edges, so as to form hollow slabs. A set of slabs are bolted together by two bolts passing through bosses, which are stamped in the sheets at the time of corrugating them; the bolt-holes in the successive bosses form two channels, through one of which the exhaust steam enters all the slabs at the top, while the other is the outlet for the condensed water from the bottom. The condensing surfaces undergo no deterioration, being exposed on the inside to slightly greasy water which is not corrosive, and on the outside to a current of dry air only. There are nine groups of ventilators and condensers, each group containing three ventilators and three sets of condensing slabs. Before entering the condensers, the exhaust steam passes through nine grease separators, from which the greasy water is drawn off by three suction-pumps. The three horizontal air-pumps drawing from the condensers have metallic clacks suitable for working with very hot water, up to 90° C. or nearly 200° F. For the same reason, and also on account of the grease, no india-rubber packing is used in any of the six pumps. The water from the condensers is filtered through charcoal filters; that from the grease separators, amounting to 2 cubic metres (4,400 lbs.) per hour, or say 9 per cent. of the steam, undergoes prolonged filtration through charcoal and afterwards through sponges. The power provided for driving the twenty-seven ventilators and six pumps is 120 HP., or less than 3 per cent. of the power of the three engines. The condenser vacuum is stipulated to range from 53 down to 24 centimetres (20·87 down to 9·45 inches) of mercury, according as the air temperature ranges from 10° up to 36° C. (50° up to 97° F.), agreeably with a specified scale of corresponding temperatures and pressures. From temperature observations made in 1897, it is anticipated that the average vacuum for the year will be nearly 40 centimetres (15·75 inches) by day and 52 centimetres (20·47 inches) by night. Only during part of the night will the engines be fully loaded, while supplying current for electric lighting; by day they will always be working more or less below full load. Half a score of similar condensers for engines of from 50 to 200 HP. have already been put up by the Author in the same country, and the results have entirely answered his expectations.

A. B.

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Steam-Hammer Diagrams. Prof. GEORGE LINDNER.

(Zeitschrift des Vereines deutscher Ingenieure, 1902, p. 37.)

The steam-hammer has not, in the Author's opinion, been sufficiently studied from a theoretical point of view, and in order to obtain information as to the actual processes going on in the cylinder, he took a number of diagrams off a steam-hammer in the railway workshops at Carlsruhe. To apply the indicator, the oil-cup at the top of the cylinder, and the drain-cock at the bottom were removed. In the experiments only wood was laid on the anvil, as the hammering of iron produced such violent jerks as to break the cords used to rotate the drum. The diagrams taken are reproduced in the Paper; their outlines are very irregular, and in some cases do not show closed curves. The compression in one diagram exceeded the pressure of admission, although the exhaust was full open. On working out results from certain of the tests, the Author found that the energy of the blow was of an amount not exceeding that due to the free fall of the hammer, that the steam-pressure above the piston had been just sufficient to overcome the friction and the back pressure.

With regard to the power obtained from the steam, the Author calculates that one HP. per hour was produced at the cost of 80 kilograms (176 lbs.) of steam.

The Author also obtained curves of pressure to a base line showing time, and to move the paper strip he abandoned the use of clockwork, regulated either by fans or a pendulum, and made use of a shaft rotating at any speed, the time scale being afterwards deduced from marks made on the Paper at regular time intervals during its rotation.

The Author concludes from his experiments that the inlet passage for the steam—in area about $\frac{1}{20}$ of the upper surface of the piston—is not large enough, and that the valve-chest should be at the lower end of the cylinder.

J. G.

The de Laval Steam-Turbine; its development, improvement and latest applications.[1] K. SOSNOWSKI.

(Revue de Mécanique, July, 1902, p. 5 *et seq.*)

Eight years ago the Author described for the first time the steam-turbine of de Laval, the first impulse turbine constructed. The confidence then expressed in it was based on theoretical grounds, which, as then stated,[2] showed that the steam-turbine

[1] Minutes of Proceedings Inst. C.E., vol. cxlviii. p. 385.
[2] Génie Civil, No. 20, 1894.

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might be made to utilize from 50 per cent. to 75 per cent. of the theoretical power of the steam, whilst the best engines of other types could yield only a third or a fourth of the amount theoretically possible. Experience has now confirmed the expectation that with improvements the steam-turbine would rival, and in many cases surpass, the most perfect piston engines.

The first installation of de Laval turbines dates only from 1892, and there are now nearly 3,000 at work, representing a total of 85,000 HP., of which nearly 40,000 are in France alone. They have been employed as motors for the transmission of power by means of belts or cables; as turbine-dynamos, or turbo-alternators for the production of electrical energy under its most varied forms, for illuminating purposes, for electrolysis, and for the transmission of power; as turbine-pumps for drainage, raising of water, fire-engine pumps, etc.; as turbine-fans for ventilating, for the blast of forges, cupolas, etc.

The steam-turbine has many advantages; its bulk and weight are very small, its installation is extremely simple, it is easy to start and stop, and regular in action, whilst the only attention it requires is that of keeping the lubricators in working order. To demonstrate the remarkable regularity of its action, the Author supplies diagrams which were taken by an automatic tachograph; these show the fluctuation of speed of the turbine as compared with a triple-expansion engine, a compound condensing engine and a gas-engine with double fly-wheels, both under constant load and also when subject to severe and sudden variations of load; and these diagrams show that the triple-expansion engine alone approaches the steam-turbine in steadiness of action.

The efficiency of the de Laval turbine does not diminish with time. The wear of the vanes, which may occur in course of years or under abnormal conditions, has only an insignificant effect on the efficiency. This is shown in Table I., which gives the results of experiments on two turbines of the same power, the one having run for 5 years, the other having a disk which was quite new. The consumption of steam in the first case was 10·067 kilograms (22·193 lbs.) per B.HP.,[1] and in the second 9·702 kilograms (21·388 lbs.), the pressure being the same in both, but the vacuum higher in the second case; so that, had it been possible to maintain the same vacuum in both instances, it could hardly be said that any increase of consumption could be ascribed to the wear and tear of the vanes. The Author cites the case of a turbine which has done 30,000 working hours without interruption. The oil consumption of an electric generating plant of 100 HP., consisting of turbine and dynamo, amounts to about 300 grams (0·66 lb.) per hour, and one of 300 HP. to barely 750

[1] In all cases the French horse-power is retained = 0·986 English horse-power.

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grams (1·65 lb.), which represents an expense of about 0·001 franc (0·0095*d.*) per horse-power-hour.

The superiority of the turbine as regards steam-consumption under variable load is exhibited by means of a diagram, which compares a compound Corliss condensing-engine with a de Laval turbine, from which it appears that the latter is more economical at all loads, its advantage in economy increasing rapidly as the load diminishes.

The Author proceeds to give instances of the applications of these turbines to various uses, and refutes the opinion commonly held that centrifugal pumps are only suitable to low lifts. With a wheel of 90 millimetres (3½ inches) diameter, running at 15,000 revolutions per minute, a discharge of 24 litres (5·28 gallons) per second was obtained at a height of 125 metres (410 feet); and at 18,000 revolutions, 190 metres (623 feet) was attained, the efficiency being 63 per cent., which might increase to over 70 per cent.

The Author predicts for single centrifugal pumps lifts of above 300 metres (984 feet), and several thousands of metres for pumps in series.

For ventilating purposes, the first experiments with a disk of 200 millimetres (7·87 inches) diameter, running at 17,000 revolutions per minute, gave a discharge of 2·3 metres (8·1 cubic feet) under a water pressure of 2·5 metres (8·2 feet), with an efficiency of over 60 per cent., the weight of the whole apparatus being 1,500 kilograms (3,307 lbs.), which shows that, with fans adapted to the speeds of the steam-turbine, as high pressures can be obtained as with piston compressors and with corresponding efficiencies.

The improvements introduced into the de Laval turbine include the following. Automatic regulation of the steam-jets, by means of the varying pressure in the steam-chamber acting upon pistons which open or close the nozzles, so as to keep the pressure sensibly constant whatever the power required.

The mounting of the vanes on the disk is so arranged that the vanes can be removed and replaced in a simpler manner than hitherto. The steam-tight fitting for the flexible shaft consists of a special bearing which is free to follow without impeding, the movements of the flexible shaft on which it is mounted, at the same time closing all communication between the interior and exterior of the machine.

The bronze gear-wheels have been replaced by steel wheels which offer great advantages over bronze. The use of solid disks, with the shaft in two pieces, permits a peripheral velocity more in accord with the velocity of the steam, and a consequent realization of higher efficiency. The results obtained with this type are tabulated from a report of experiments on two three-phase turbo-alternators of 300 HP.

Tables II., III. and IV. give the results of tests on 300-HP. turbines, under different loads, the last two sets with superheated

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steam. In respect to this, the following results are given from experiments carried out in 1900.

	Consumption of Steam per B.HP.
100 HP. turbine, 7 kilograms pressure per square centimetre (100 lbs. per square inch) without superheat	9·80 kilos.
100 HP. turbine, 15 kilograms pressure (215 lbs. per square inch) with 60° C. superheat	6·42 „
300 HP. turbine, 15 kilograms pressure (215 lbs. per square inch) with 60° C. superheat	5·32 „
15 HP. turbine, 15 kilograms pressure (215 lbs. per square inch) with 60° C. superheat	16·8 „

At the outset the Author considered only the advantages to be derived from the use of high-pressure steam. These advantages are shown in Fig. 18, which shows steam consumption per brake-horse-power hour plotted as a function of the inlet and outlet pressures. With dry saturated steam at 10 kilograms to 15 kilograms pressure (142 lbs. to 213 lbs. per square inch), such as is now in common use, experiments show a consumption of 8 kilograms to 7 kilograms of steam (17·6 to 15·4 lbs.) per B.HP., a result which agrees well with the curves; but, so far as the turbine is concerned, there is no reason why these pressures should not be increased, the best proof of which is the fact that at the Stockholm Exhibition, in 1897, the central electric-generating station was exclusively equipped with these turbines, working under a mean pressure of 150 atmospheres (*sic*, ? 15).

Superheating, however, has now lent its aid to effect still greater economy. Formerly it was thought impossible to carry this beyond 375° C., but it has now been shown that it can be carried to 500° C. in the de Laval turbine with surprising advantage, and the Author in Table V. gives the results[1] (quoted from the *Zeitschrift des Vereines deutscher Ingenieure*) of experiments made last year in the Laboratory of the higher technical school in Dresden on a 30-HP. turbine, in which the superheat was pushed to 500° C. at a pressure of 6 atmospheres at the turbine, with a resulting gain of 30 per cent. in economy as compared with saturated steam.

An examination of the figures given shows that with increased superheat not only the consumption of steam, but also of heat per brake-horse-power diminishes as the load increases. We conclude from these results that the useless work is diminished in consequence of the small friction of the wheel in the superheated outlet steam, and that there is an increase of energy in the jet per unit weight of steam. This energy, we know, increases as the square of the speed, which is proportional to the quantity of steam passing the nozzle in unit time. To this gain of fluid energy there corresponds, indeed, a decrease of the so-called hydraulic effect; for an increasing velocity (which, *e.g.*, in the last experiment of Table V. was 807 millimetres (2,650 feet) per second for saturated steam, and 1,046 millimetres (3,430 feet) per second for the super-

[1] Minutes of Proceedings Inst. C.E., vol. cxlviii. p. 384.

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heated steam) and for a constant peripheral velocity of the wheel, this must diminish in consequence of the increase of loss by shock. However, this diminution of the hydraulic action is only of secondary importance, as the experiments show; for on account of the increase of shock at inlet, the temperature of the steam in the outlet chamber is found to be raised, and this lowers the resistance, and, at the same time, increases the mechanical effect. This increase of temperature due to impact was demonstrated by a special series of experiments, the results of which are given in Table VI. Table VII. shows the work lost when running simply in air, in saturated steam and in steam superheated to different amounts, by which it is clearly shown that the frictional loss of the wheel in saturated steam is 1·3 HP. less than in atmospheric air, and that this loss, with the outlet steam superheated to 300° C., falls from 3·3 HP. to 1·88 HP. The advantage of condensation in this respect is also clearly marked.

The losses in the steam turbine are all extra-thermodynamical, except that due to the absence of adiabatic compression of the outlet steam necessary to pass from the Rankine-Clausius to the Carnot cycle. These losses consist of the friction of the bearings, of the disc in the medium surrounding it, loss by leakage, and by incomplete expansion. The turbine is, however, almost entirely free from the most important of extra-thermodynamical losses of ordinary steam-engines, viz., the action of the walls.

The future of the steam turbine outside its special applications lies before everything else in the use of superheated steam.

E. H. S.

Theory of Ejector-Condensers, with Experiments on a new type of this Apparatus. A. RATEAU.

(Revue de Mécanique, June, 1902, p. 533, etc.)

That the ejector-condenser has not received more attention since its invention by Morton, in 1867, the Author ascribes to the fact that hitherto its action has been unreliable and its vacuum unsatisfactory. He points out, however, that it offers great advantages, especially in the case of high-speed engines and steam-turbines, on account of its independent action and the absence of any piston.

The Author's present contribution is complementary to the general theory of pumps already published by the Author in the *Revue de Mécanique* for September, 1900. It is shown, by mathematical treatment, that the ejector-condenser, like the injector, depends for its action on the principle of the conservation of momentum, the momentum of the exhaust steam, on account of its high velocity, being comparable with that of the condensing water which it impels, so long as the ratio of steam to water is not reduced below a certain limit; but if this limit be passed, the momentum of the steam falls rapidly to zero, and the action of the

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ejector ceases unless the momentum of the discharge be increased. This may be done in three ways: 1st. By admitting an additional supply of steam, either into the body of the ejector, or perhaps better, into the water-nozzle; but as this method is wasteful, it is desirable to apply it only in very special cases. 2nd. By reducing the cross-sectional area of the steam-supply, so that its velocity is increased. This plan is adopted by the firm of Koerting, but is only applicable within narrow limits. If, however, the exhaust steam is liable to fall (as in the case of engines running empty), to about 15 per cent. of the discharge at full load, there remains only: 3rd. To feed the ejector with water under pressure; or 4th. Instead of increasing the total momentum, to diminish the pressure of the water-supply, by raising the ejector to a greater height above the discharge tank.

If it were not for the vitiating effect of air entrained in the discharge, an almost perfect vacuum might be produced, but as the quantity of gaseous fluid increases, the mean specific weight of the discharge rapidly decreases, on account of the very low pressure which exists in the neck of the ejector. In order to show more clearly the injurious effect of air, the Author has constructed an abak showing the pressure as a function of the quantity of air for different initial pressures in the neck of the apparatus; from which it is evident that a very little gaseous fluid suffices to lower the energy of flow and to stop the action of the ejector; also, when the energy is constant, the pressure in the neck rises as the quantity of air increases.

It is found that, for an apparatus working with a definite difference of water-pressure between the inlet and outlet, the difference between the steam temperature and the temperature of discharge is sensibly constant (about 20° C. at full load), whatever the quantity of steam condensed. This law the Author illustrates by means of curves. When, however, the auxiliary water-jets are opened, this difference is a little greater, amounting to 26° C. in the case of the ejector tested; probably because the steam finds more difficulty in penetrating to the centre of the stream. When the peripheral surface of the jet is increased, so that the surface in contact with the steam is greater, this difference of temperature is less. Consequently, to obtain a good vacuum, the mixing chamber must be lengthened, and the jet divided into thin laminæ, care being taken at the same time to maintain a proper form of discharge into the conical outlet-pipe.

The Author next illustrates and describes his form of ejector-condenser. This consists of a lateral steam inlet, curving into the mixing chamber, into which a centrally situated nozzle throws the cold water, the condensed steam and water flowing in a convergent stream through the neck of the apparatus into a pipe, which expands outwards. In cross-section the injection nozzle has the appearance of a many-rayed star, which projects the water in a fluted vein, whose perimeter is about three times that of the circular vein having the same area, so that the steam is rapidly

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condensed. With the object of economy, the water-supply can be regulated by means of auxiliary inlet tubes, and this is done either by hand or automatically.

When there is no water-supply under pressure for feeding the ejector, it is necessary to use a small centrifugal pump giving an average head of 5 metres (16 feet), the power of driving which is estimated at less than 2 per cent. of the power of the engine.

The Author then describes his experiments, which consisted in measuring under normal conditions, and under conditions which were varied at will: 1. The electrical power performed by the machine (by means of a voltmeter and ampere meter); 2. The vacuum given by the ejector; 3. The temperature of inlet and outlet of the water; 4. The water-pressure at inlet, and the height of suction at the outlet.

The experiments are carefully tabulated and plotted. The Author concludes by comparing his ejector with an ordinary jet-condenser, and shows that the vacuum is sensibly the same up to a temperature of about 30° C. of the outlet, but that the ejector is less effective as the temperature rises. At ordinary working temperatures of about 35° C., the difference is only about 0·05 kilogram per square centimetre (0·7 lb. per square inch) for the same amount of condensing water.

Illustrations are given showing the ejector applied to a compound engine, and to a steam turbine. On account of its simplicity, it can readily be applied to engines of small power, down to 10 HP. or 15 HP., and with equal ease to engines of larger size, condensing readily 20,000 kilograms (44,000 lbs.) of steam and more per hour, or it can be combined with ordinary condensers, or with barometric condensers, such as have been in favour recently in Germany, which consist of a long tube more than 10 metres (33 feet) long, from which the water issues by its own weight.

By means of a steam accumulator placed between the engine and condenser, the Author shows how his apparatus may be successfully applied to the case of large machines subject to intermittent action.

E. H. S.

Design of Two-Cycle Gas-Engines. R. Barkow.

(Zeitschrift des Vereines deutscher Ingenieure, 1902, p. 81.)

In the two-cycle gas-engine the scavenging and charging strokes are omitted. The explosion and expansion take place on the outward stroke, and in the return stroke the products of combustion are ejected and a fresh charge introduced by a separate pump, and this operation completed in time to allow of the compression of the charge in the same stroke.

Let the volume at the end of expansion be denoted by v_e, the

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volume at the moment of completion of the charging operation and compression by v_f, and the volume at the end of compression by v_c. Calling ϵ_1 the ratio of compression, it can be expressed as a factor of the ratio of expansion for the four-cycle engine, thus: $\epsilon_1 = \psi \epsilon$. Calling p_e the pressure of explosion and p_o the pressure during exhaust and charging, the constants for the expansion and compression lines have the respective values $p_e v_c^k$ and $p_o v_f^k$. The mean pressure may be expressed, in terms of the symbols just given, in the equation—

$$p'_m = \frac{1}{v_c(\epsilon - 1)} \left\{ \frac{p_e v_c}{k-1} \left(1 - \left(\frac{1}{\epsilon}\right)^{k-1}\right) - \frac{p_o v_f}{k-1} \left(\epsilon_1^{k-1} - 1\right) - p_o v_c (\epsilon - \epsilon_1) \right\}$$

By means of the following two equations, which connect the pressure with the energy of the charge Q ($Q^1 = \eta_e Q$ being the effective energy) and this in turn with H, the heating value of the gas per cubic metre:—

$$Q^1 = \eta_e Q = \frac{A}{k-1} (p_e v_c - p_c v_c)$$

$$Q = \frac{H}{1+a} v_c (\epsilon_1 - 1)$$

(a is the proportion of air to gas in the charge) the value of the mean pressure can finally be obtained and expressed as a function of values known to the designer.

$$p'_m = \eta_i \left\{ \eta_e \frac{H}{1+a} \left(1 - \left(\frac{1}{\epsilon}\right)^{k-1}\right) \frac{1}{A} \frac{\psi \epsilon - 1}{\epsilon - 1} + \frac{p_o \epsilon}{(\epsilon - 1)(k-1)} \left[\psi (2-k) + k - 1 - \psi^k \right] \right\}.$$

Deducting from this p'_m the indicated mean pressure of the air pump p''_m, the value of p_m, the effective mean pressure, is finally arrived at.

It is evident that $\psi = 1$ represents the case of the four-cycle engine. The Author discusses the effect of variations of ψ and ϵ, showing the benefits of a high degree of compression, but also pointing out the limits to this arising from the great strain on the piston, piston-rod, and bearings, and the increasing mass required in the fly-wheel. It is next shown that the compression volume and the temperature of the burnt gases have no influence on the amount of the charge.

The Author finally investigates the degree of compression which must be used, in order, with a given charge, to secure explosion and complete combustion, bringing in the average distance between the molecules of the gas and the temperature as the two principal factors. J. G.

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The New Diesel Engine.

(The Engineer, 30 May, 1902, p. 528.)

Great structural simplifications have recently been made in this form of oil-engine, which considerably increase its mechanical efficiency.

So far the vertical inverted type has been principally developed, twin cylinder engines of this form having been built up to 200 HP.

An important innovation in the design is the introduction of a water-jacket, which was not a feature of the original engine; its application has been found to thicken out the diagram to an important extent.

The cylinder lining is dense cast-iron; it is set into an outer casing so as to leave a space between the two for a water-jacket. This casing is cast in one piece with the two legs of the standard frame, which is firmly bolted to a stiff bed-plate carrying the two main crank bearings. The cylinder has its lower end open and the piston is of the trunk pattern. The cylinder cover is very deep and in it are cast four valve boxes, the remainder of its interior space being available for a water-jacket. Two of these valves, of the mushroom type, serve for the air inlet and the exhaust; they open downwards against springs by means of cranked levers and roller cams. The oil is introduced through the central plug-valve, which is opened when a cylinder full of air has been compressed, being blown in through a sprayer by a small charge of air, compressed to about 100 lbs. per square inch above the pressure then in the cylinder. This air is compressed by a small pump which draws from the main cylinder during the compression stroke and delivers into a cylindrical reservoir. This store of compressed air is also utilized for starting the engine by admitting it through the fourth valve in the cover.

This type of engine can utilize the crudest oils with as much facility as refined oils, for the compression of the air is carried to such a point that its temperature is sufficiently high to cause the injected oil spray to burn quietly and completely as it enters. The governor regulates the quantity of oil injected at each double stroke, consequently explosions are not missed and the running is therefore very uniform.

A. W. B.

Blast-Furnace Gas-Engines at Ilsede Ironworks.

(Stahl und Eisen, vol. xxii., p. 898, 15th August, 1902.)

The introduction of electric generators driven by blast-furnace gas through the medium of steam-power at Ilsede dates back to 1899, when five engines, one of 170 HP., three of 300 HP., and

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one of 750 HP. were provided for working alternators at 500 volts and collectively of 1,200 kilowatts. For lighting and other purposes at the furnaces 150 kilowatts are employed, at the initial pressure. The remaining 1,050 kilowatts are raised to a voltage of 10,000, of which 100 kilowatts are sent 3½ kilometres in one direction to the ore workings at Gross Bulten to serve an underground pumping engine, six rock-boring machines, a mine locomotive and a ropeway, in addition to lighting the works. The remaining 950 kilowatts go to the Peine steel works, 6½ kilometres distant, where they drive a small bar rolling mill, several live roller trains, the machinery of the open-hearth furnaces, the basic-slag mill, and the yard loading-cranes. Subsequently, experiments having been made with a small gas-engine which proved successful, a large building, 45 metres by 65 metres, to contain six gas-engines of 1,000 HP. each, has been erected. In order to obtain sufficient gas, it is intended to substitute gas-blowing engines for those driven by steam, and the first of these has lately been set to work, while a second is under construction. They are of the Oechelhäuser pattern, with a single-power cylinder working the blowing cylinder directly. The air-cylinder has a capacity of 128 cubic feet per revolution, and when worked at 100 revolutions per minute requires about 600 HP. The blowing pressure is from 7½ lbs. to 12½ lbs., the suction-valves being arranged so as to diminish the volume aspirated at the higher pressures in order to keep the load on the engines as uniform as possible.

In the new power station two pairs of Oechelhäuser twin engines, without fly-wheels, developing 1,000 HP. each, are provided for working Siemens and Halske 10,000-volt alternators. The new station is to be worked in parallel with the older steam-driven one, and it is intended ultimately to provide 6,000 HP. for the Peine rolling mills. This, when completed, will, with those at Hörde and Differdingen, be the most important blast-furnace gas-engine plants in existence.

H. B.

Wear and Friction of Toothed Wheels. K. Büchner.

(Zeitschrift des Vereines deutscher Ingenieure, 1902, p. 159.)

The General Electric Company of Germany has been successful in producing toothed gearing to run at a peripheral speed of 12 metres (39 feet 4 inches) per second, with satisfactory results in regard to durability and quiet running. This result is due to a more accurate knowledge of the circumstances affecting the wear of wheel teeth, and these the Author further considers in his Paper. The action between wheel teeth consists of rolling and sliding, and, in addition, impact due to the irregular motion. Suppose two teeth in contact at the point A, and let C_1 and C_2 be points

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on the driving and driven teeth respectively which ultimately come into contact further along the line of contact. Calling $A C_2 = ds_2$ and $A C_1 = ds_1$, the specific slides for the two teeth are:—

$$\gamma_1 = \frac{ds_2 - ds_1}{ds_1} \text{ and } \gamma_2 = \frac{ds_2 - ds_1}{ds_2}.$$

Dividing these expressions by the element of time, dt, γ_1 and γ_2 are obtained as functions of the velocities, $v_1 = \frac{ds_1}{dt}$ and $v_2 = \frac{ds_2}{dt}$, with which the point of contact moves along the flanks. As a point on the driving-wheel, A moves along $A C_1$, and also simultaneously along the line of contact to B, the point in which C_1 and C_2 ultimately meet; similarly considering A as a point on the driven wheel, its motion may be compounded of $A C_2$ and $C_2 B$. These considerations give at once a method of obtaining graphically the laws of variation of the velocity of the point of contact along the flanks, and from this the specific slide for each point on the tooth. The Author exhibits curves of the specific slide for various forms of wheel teeth, and also gives analytical methods of finding the values of γ for cycloidal and involute teeth. The normal pressure N between the teeth is also considered by the Author, and his diagrams show that it is increased by the friction during the approach of the teeth to the pitch point, and decreased when receding from it. Putting n for the number of revolutions per minute, the Author next proceeds to form the products, $N\gamma_1 \frac{n_1}{n_2} = N\gamma_1 \epsilon$ and $N\gamma_2$, and draws curves showing the variation of these quantities along the faces of the teeth. These curves he designates characteristics of wear, and the conclusions to be drawn from them, as to the way in which teeth of the various forms wear, coincide with practical experience. The Author shows that both cycloidal and involute teeth should be as small in size and as large in number as possible, and that the diameter of the rolling circle for describing the flanks of cycloidal teeth should also be small. The Author further discusses the work of friction, and the influence of the diameter of the wheel, and the width of the teeth on the durability.

J. G.

Vertical Compound Air-Compressor. R. GOETZE.

(Zeitschrift des Vereines deutscher Ingenieure, 1902, p. 155.)

The type of compressor employed in the Westphalian mining district has changed considerably in recent years, and the one described in this Paper is unique in being vertical. There is an air- and a steam-cylinder at each end of the machine, the former

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on the outside. The main dimensions are:—diameters of air-cylinders, 950 millimetres and 590 millimetres (37·4 inches and 23·2 inches); diameters of steam-cylinders, 685 millimetres and 1,025 millimetres (27 inches and 40·3 inches); stroke 900 millimetres (35·4 inches); maximum revolutions per minute, 85. The contracting firm guaranteed that at 85 revolutions the machine would compress 6,000 cubic metres (211,900 cubic feet) per hour from atmospheric pressure to a final pressure of 6 atmospheres (85·3 lbs. per square inch), the power exercised by the steam-cylinders being from 635 HP. to 675 HP. The volumetric efficiency was to be from 92 per cent. to 96 per cent., and the mechanical efficiency 79 per cent. to 83 per cent. The four cranks are set at right angles to each other, the high-pressure steam being opposite the high-pressure air-crank. Owing to this arrangement, the fly-wheel is comparatively light. Regulation is effected by means of an expansion valve on the rider piston-valve of the high-pressure steam-cylinder. For each air-cylinder there is a piston valve worked by a small crank off the main shaft, and a self-closing valve at each end of the cylinder. The valve motion has proved itself particularly suited for a high rate of revolution. The work absorbed by the piston valve as obtained from diagrams is about 2½ per cent. of that indicated on cards taken from the air-cylinders. The air is cooled when passing between the two cylinders by being sent through a cooler with 120 brass tubes containing the cooling water. From tests made, the temperature at the various points was found in one case to be as follows:—external air, 4·5° C.; air on entering the cooler, 122° C.; on leaving the cooler, 24° C.; temperature of the final compressed air, 104° C.

When tested on delivery, the air drawn in measured 6,400 cubic metres (226,000 cubic feet) per hour, and this was compressed to 6·8 atmospheres (96·6 lbs. per square inch) absolute, at a cost of work in the air-cylinders and valve-chambers of 573 HP. The total steam-power indicated in the two cylinders was 662 HP., the resulting dynamic efficiency being thus 86·5 per cent.

J. G.

The 5,500 *HP. Turbines for the Niagara Falls.*

(Schweizerische Bauzeitung, 1902, p. 67.)

The original article describes the power-station at the Niagara Falls, which has already been dealt with in the American and British technical journals; but it also contains a detailed description of the hydraulic regulators upon the turbines, which are of special interest. In 1900 the Falls Company decided to order turbines each of 5,500 HP. from Messrs. Escher, Wyss, and Company, and these were to run at 250 revolutions per minute, and the available head of water was from 144 feet to 161 feet; it was also desired to obtain as silent running as possible. The turbine

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wheels and the regulator gear were to be made in Zurich, and the rest of the work in the United States from the Swiss designs. The turbine is of the Francis type, with only one wheel of 5·25 feet diameter, and the water enters the case through a tube 7·44 feet diameter. The wheel consists of a single casting of Manganese bronze, and regulation is effected by means of an annular case, which is movable in a vertical direction between the wheel and the guide vanes by means of two vertical rods. The pressure upon the bottom footstep of the vertical shaft is relieved by means of water under pressure.

The regulator, which is illustrated in the original, is of the oil-pressure type, with Servo-motor of the patent form, designed by Messrs. Escher, Wyss, and Company. The balancing of the rod acts upon a two-armed lever, and thence upon the piston of the Servo-motor, which has merely to open the turbine, while the closing is effected by the balance-weight, and by the weight of the parts of the apparatus. Below the regulator-valve there is another valve actuated by electric energy and controlled from the switchboard. There is also a hand gear for regulation in case of necessity, details are given in the original.

E. R. D.

A Reversing Cogging-Mill with Compound Condensing Engines.

W. SCHNELL.

(Stahl und Eisen, vol. xxii., 1902, p. 413.)

This mill, which is fully illustrated with dimensioned drawings in Plates V. to VII., has been built by the Märkisch Maschinenbau Anstalt of Wetter on the Ruhr, for the Röchling Steel and Iron Works at Volklingen on the Saar, and presents several novel features in the design. The rolls, 45 inches in diameter and 9 feet long, take ingots of 22 inches by 17 inches maximum size and 4 tons weight, and give a minimum reduction to about 5½ inches square. The driving engines, a pair of horizontal tandem compounds, with cylinders 37·4 inches and 63 inches diameter, and 51·2 inches stroke, make 120 revolutions per minute, which are reduced by spur gearing to 48 revolutions in the rolls. The top roll is provided with hydraulic counterpoises, and the top coupling spindle with balance levers and weights. The housings, both of the mill and the pinions, are rigidly connected by cross bracings, formed of hollow box castings connected by steel binding rings shrunk on. The pinion housings are placed within the engine-house upon the main bed-plate, and are completely covered in; the pinions running in an oil bath. The live roller train feeding the mill is raised about 3 feet above the ground-level, and driven by a pair of inverted cylinder vertical engines, 14 inches diameter and 20 inches stroke, a somewhat unusual size,

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which, however, is rendered necessary by the variation in the available steam-pressure, which ranges from 105 lbs. to as low as 60 lbs. per square inch. The hot bloom shear, of the direct-acting steam-driven hydraulic form of Messrs. Breuer Schuhmacher and Co., is placed 65 feet in front of the mill, with its own roller train and a combined delivery system for the different products. The first of these, an electric-driven bucket elevator, takes crop ends and billets and loads them into small wagons for removal. The second, a combined hydraulic pusher and lifting table, carries the larger blocks to a carrier for the finishing mill, while the third passes the sheared blooms by an inclined plane to an electric travelling crane, which feeds the heating furnaces of the girder mill. The total length of the mill is about 128 feet, and the greatest breadth across the mill and engine-house about 66 feet, the whole area being commanded by two traversing cranes placed at different levels, with their paths at right angles to each other. The lower one, which is driven by an electromotor, has a lifting power of 40 tons, and serves the new cogging mill as well as an older one, and the driving gear of the main engine, so that roll, changing and repairs on the driving pinions are rapidly effected.

H. B.

On De-Sulphurizing Cast Iron in the Foundry Cupola.

P. Reusch.

(Stahl und Eisen, vol. xxii., 1902, p. 415.)

This Paper records some experiments made at Witkowitz on the possibility of removing sulphur from foundry iron, as well as taking up that contained in the coke used in the cupola by the addition of a manganiferous flux. The experiments were made in a small cupola, 19½ inches in diameter, using a high charge of coke in order to facilitate the taking up of sulphur by the metal. The iron used in each experiment was 6 cwt., charged in quantities of 2 cwt. 5·6 cwt. of coke were used for filling the cupola, and about ¾ cwt. was added with each round of metal. The cupola was tapped three times during each melting, about 2 cwt. being drawn each time. Samples were taken from the middle of each running and analyzed separately.

The composition of the different materials employed was as follows:—

Foundry Pig Iron.

Total carbon	3·81
Graphite	3·07
Silicon	1·93
Manganese	0·92
Phosphorus	0·18
Sulphur	0·006

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Coke.

Ash	11·10
Sulphur	0·81

Manganese Ore.

This is a manganiferous clay slate containing—

Iron	2·87
Manganese	27·72
Phosphorus	0·11
Sulphur	0·36

The composition of the limestone was not determined.

The results of the different experiments were as follows—

Table I.—Without Lime or Ore.

	Samples.		
	1	2	3
Carbon	3·58	3·60	3·50
Silicon	2·04	2·09	2·03
Manganese	0·79	0·72	0·72
Phosphorus	0·22	0·22	0·21
Sulphur	0·05	0·04	0·056

Table II.—With 2 per Cent. of Lime.

	Samples.		
	1	2	3
Carbon	3·18	3·51	3·45
Silicon	2·07	1·91	1·91
Manganese	0·70	0·70	0·68
Phosphorus	0·22	0·24	0·26
Sulphur	0·06	0·074	0·080

Table III.—With 4 per Cent. of Lime.

	Samples.		
	1	2	3
Carbon	3·55	3·74	3·70
Silicon	2·09	2·04	2·12
Manganese	0·75	0·75	0·77
Phosphorus	0·23	0·22	0·22
Sulphur	0·06	0·038	0·045

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TABLE IV.—WITH 1 PER CENT. OF MANGANESE ORE AND 2 PER CENT. OF LIME.

	Samples.		
	1	2	3
Carbon	3·44	3·37	3·60
Silicon	2·12	2·05	2·11
Manganese	0·82	0·82	0·82
Phosphorus	0·23	0·25	0·23
Sulphur	0·007	0·004	0·006

TABLE V.—WITH 2 PER CENT. MANGANESE ORE AND 4 PER CENT. LIME.

	Samples.		
	1	2	3
Carbon	3·72	3·64	..
Silicon	1·91	1·99	..
Manganese	0·77	0·84	..
Phosphorus	0·21	0·20	..
Sulphur	Trace	Trace	..

TABLE VI.—WITH 3 PER CENT. MANGANESE ORE AND 6 PER CENT. OF LIME.

	Samples.		
	1	2	3
Carbon	3·57	3·66	3·55
Silicon	1·88	1·96	1·90
Manganese	1·02	1·01	0·97
Phosphorus	0·21	0·20	0·20
Sulphur	Trace	Trace	Trace

As a result of these experiments it has been found that coke that is too high in sulphur to be suited for foundry use, can be made perfectly serviceable by adding a proportion of manganese ore to the coal before introducing it into the coke oven. Coke so prepared, when used for remelting in the cupola, although containing 2 per cent. of sulphur gave up none of it to the metal.

H. B.

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A New Method of Concentrating Sulphide Ores. A. FROMENT.

(Rassegna Mineraria, July, 1902. Oesterreichische Zeitschrift für Berg und Hüttenwesen, 1902, p. 441.)

This is a development of the Elmore process of separation by oil. The Author has observed that when finely-powdered sulphides are immersed in oily fluids they tend to coalesce into balls and float up to the surface, the flotation being only retarded by their density and the resistance offered by the associated waste minerals. If, however, gas is evolved in such a mixture, the bubbles as they rise become completely coated with sulphide particles and collect at the surface as a thick scum or paste, free from the suspended waste. The operation is most effective when the gas is brought into contact with the mineral in the nascent condition, i.e., when developed in the mixture. For instance, if 10 grams of the mixed mineral finely powdered are mixed with 1 gram of limestone and 30 grams of water, to which a thin layer of oil has been added, together with a few drops of sulphuric acid, and the whole shaken together for a few seconds, the bubbles pack closely together, floating the copper pyrites up to the surface. If the limestone is in excess or too easily soluble the action is so energetic that the whole of the mineral may be projected in froth, the rapidity of formation of the bubbles being regulated by the amount of gas produced in a given time. The small quantity of waste which is carried over mechanically subsides when the mixture is allowed to settle, leaving the sulphides almost completely pure. A mixed mineral containing 12 per cent. copper pyrites, 15 per cent. iron pyrites, 20 per cent. spathic iron ore, 16 per cent. dolomite and calcite, and 37 per cent. of other waste minerals which could not be concentrated by any process actually in use, when subjected to the new method, gave a completely clean concentrate of copper pyrites in a few seconds, the residues being found to be perfectly free from copper by analysis. Clean separation of copper pyrites from iron pyrites is also effected, the latter mineral remaining in the waste. The method is under trial for the treatment of the mixed lead, zinc and pyritic ores of Sardinia, and from the experiments, as far as they have gone at present, it appears that in lead ores associated with arsenical and antimonial minerals a complete separation of the former may be obtained. The ore and oil magma obtained is subjected to pressure, and washing in a filter press, which delivers the mineral in moulded blocks suitable for calcination; the loss of oil is about 11 lbs. per ton of material treated.

H. B

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The Alumino-thermal Process for producing high Temperatures.

(Annalen für Gewerbe und Bauwesen, 15 June, 1902, p. 229.)

The process of Dr. Hans Goldschmidt for the attainment of high temperatures depends upon the fact that if a mixture of finely divided aluminium and a metallic oxide is ignited at any point, violent combustion of the entire mass takes place with the production of a temperature 3,000° C.; the metal is eliminated in the pure state, free from carbon, and the alumina is converted into a slag, constituting an artificial corundum. The metallic oxide, which is mainly employed in this process, is that of iron, and the use of this mixture, the so-called "thermit," results in the production of malleable iron. The Author specifies and illustrates a form of simple apparatus for utilizing thermit for welding pipes, rails, etc., *in situ*. This consists of a mould, capable of being clamped on to the pipe or rail into which the molten metal can be introduced, or the aluminium mixture may be ignited in a crucible of special construction, with a perforated bottom, which is here illustrated and described, and subsequently run into the mould. The thermit is also very valuable for the repair of castings, and indications are given of the mode of using this material for a variety of industrial operations, such, for instance, as mending toothed wheels. The substance can likewise be added in small quantities to molten metal in the cupola furnace employed for casting purposes, in order to introduce limited amounts of titanium. It may also take the place of the electric furnaces for fusing refractory metals, and for making alloys of manganese, chromium, etc. In another direction, this mixture can be employed for the manufacture of an artificial corundum of extreme hardness, technically termed "coruby."

G. R. R.

Sea-going Bucket-Dredger. E. Kleinrath.

(Zeitschrift des Vereines deutscher Ingenieure, 1902, p. 552.)

This dredger, constructed to the order of a German firm, for work in China, was built as a sea-going twin-screw steamship, under the inspection of the Bureau Veritas. The hull is almost entirely of 8 millimetres ($\frac{5}{16}$ inch) plating, and is divided into eleven watertight compartments by bulkheads of 6 millimetres (0·236 inch) plating. The dimensions are:—length, 45 metres (147·6 feet); breadth, 8·5 metres (28 feet); depth, 3·6 metres (11·8 feet). The well for the ladder commences at about the centre of the length, and is open backwards, so that the vessel can cut its own flotation. With the ladder at an inclination of 45° to the horizontal, the buckets can dredge to a depth of 11 metres (36 feet); in exceptional circumstances this depth may be increased to 18 metres (59 feet). The buckets, of steel plate, having a

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capacity of 500 litres (17·7 cubic feet) are of an unusual form ; the bolt-holes at the back are lined with manganese steel, and the bolts are also of the same metal. There are two main engines of 250 HP. each, and the steam for these and for the winches working the ladder, mooring chains, etc., is obtained from two boilers of 90 square metres (970 square feet) heating surface. The ratio of grate area to heating surface is 1 to 28. All the steam-pipes are of copper. Floating discharge pipes are provided by which the dredgings, after having been finely divided by a cutting-machine and mixed with water, may be discharged on land at a distance of 500 metres (547 yards), and at a height of 4 metres (13·1 feet) above sea-level. The dredger can also be worked as a suction-pump dredger, discharging through the floating pipes. The guaranteed performance of the dredger is 300 cubic metres (392 cubic yards) per hour.

The Paper is accompanied by a Plate, and figures in the text, the general arrangement and details of the floating discharge pipes being particularly detailed.

J. G.

Resonance Vibrations in Propeller Shafts. H. Frahm.

(Zeitschrift des Vereines deutscher Ingenieure, 1902, p. 797.)

The explanations put forward for the mysterious fractures of propeller shafts have been mostly based on supposed flaws in the metal or sudden obstructions encountered by the propeller. In order to determine the actual stresses suffered by such shafts, the Author was entrusted with the carrying out of the investigations which form the subject of this Paper. The appearance of the fractured surfaces of shafts points to the action of intense stresses, but as the mean stress on shafting is usually chosen at from 200 kilograms to 230 kilograms per square centimetre (1·27 ton to 1·46 ton per square inch) and the crank-effort diagrams do not generally show more than 50 per cent. variation from the average, the Author directed his investigations to the discovery of dynamic effects, and particularly to the manifestation of phenomena similar to those of resonance in acoustics. The torsion strains on the shafts were determined by fixing strips of zinc to the outside surfaces of two of the flanged couplings at some distance apart, on which strips marks were made by platinum needles as the shafts revolved. The interruption of this marking at equal intervals of time gave the means of calculating the strains on the shaft as well as the speed of running and its variation. Incidentally to the investigation, the shear modulus of steel of 40 kilograms to 47 kilograms (25·4 tons to 29·8 tons per square inch) strength and 20 per cent. extension was found to be 828,000 kilograms per square centimetre (5,258 tons per square inch) and to vary astonishingly little.

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The phenomena akin to resonance were recognised whenever the diagrams taken on the zinc sheets were plotted to cartesian co-ordinates, the result being that the maximum stress was in one case about three times the average amount, and the stress varied from positive to negative shear. This high value alternating with the negative shear may occur three times in every revolution. The occurrence of these resonance phenomena is very much favoured by the engines being run at what the Author terms the critical speed. The critical speed of the first order is the speed corresponding to the period of free vibrations of the shaft together with the masses attached to it. The critical speeds of the second and third orders are those whose periods are twice and three times the periods of the natural vibration of the shaft. The critical speed of greatest importance is that one the order of which is the same as that of the component harmonic curve of the crank-effort diagram which has the greatest amplitude.

In the course of his experiments the Author, using the shafts virtually as spring dynamometers, measured the effective power of the engines, and also obtained thus their mechanical efficiency, which varied from 88 per cent. to 93·5 per cent. The efficiency both of the engines and propellers is detrimentally affected by the presence of vibrations in the shafting.

The Author supplies practical details of his methods of procedure in the actual testing, and also enters into the mathematical treatment of the subject at length.

J. G.

Relation between Volume of Rainfall and Total Effluent Water.

A. OELWEIN.

(Zeitschrift des Oesterreichischen Ingenieur- und Architekten-Vereines, vol. liv. p. 532.)

In estimating the cubical content of valley reservoirs for supplying the upper levels of canals, it is customary to assume the amount of water available to be about 40 per cent. of the total rainfall. That this is not universally applicable, however, the Author shows by the data collected during twelve years in connection with the Iglau Waterworks, the effluent averaging only 27 per cent. of the rainfall (maximum 44, minimum 14 per cent.). The district is in a raw climate, the average rainfall is 22·85 inches (583 millimetres), and the soil averages only about 5 feet in thickness, resting on granite and gneiss rock. In dry years the useful volume of water sinks to 14–18 per cent. of the rainfall. Altogether, after allowing for existing water-rights, it would appear that the above-mentioned assumption is too high; and, furthermore, that the estimate must not be based on mean figures, but only on averages from the minimum rainfall.

C. S.

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Some Statistics dealing with Evaporation, Rainfall, and Delivery of Streams in Devonshire.

W. INGHAM, Assoc. M. Inst. C.E.

(Transactions of the Devonshire Association for the Advancement of Science, Literature, and Art, vol. xxxiii., 1901, p. 500.)

In this Paper appear the results of measurements of the evaporation from the surface of a tank at Kennich, Devonshire, situated 836 feet above Ordnance datum, for the 4 years 1897 to 1900 inclusive. The average yearly evaporation for the 4 years was 20·88 inches, and the ratio of the evaporation to rainfall 50·81 per cent. Records of the rainfall on the Torquay watershed, situated between 700 and 1,170 feet above Ordnance datum, for a period of 23 years are also given. The average yearly fall for that time was 41·19 inches, the driest year being 1887, when the rainfall was 27·54 inches or 66·86 per cent. of the mean; the two driest years were 1892 and 1893, when the rainfall was 80·86 per cent. of the mean, and in the three consecutive driest years, 1887, 1888 and 1889, the rainfall was 83·24 per cent. of the mean. The wettest year was 1882, when the fall was 24·20 per cent. greater than the mean. The average evaporation and absorption per year amounted to 16·11 inches.

The maximum flood discharge from the 961 acres was on the 14th February, 1883, when it reached 52 cubic feet per second per 1,000 acres.

The lowest discharge was on the 17th August, 1896, when it was reduced to $\frac{1}{8}$ cubic foot per second per 1,000 acres.

A. W. B.

Foundations in Sandy and Watery Ground. A. CASSE.

(Mémoires de la Société des Ingénieurs Civils de France, 1901, p. 562.)

In 1886 so much trouble and expense were incurred in sinking with wrought-iron tubbing a well only 5 metres (16½ feet) deep, for draining a bed of sand of large extent, that the Author was led to devise for similar future work a hollow water-curb or ring, to take the place of the usual tapered cutting-ring round the bottom edge of the tubbing. Jets of water under 4 or 5 atmospheres pressure are forced out through a series of holes in the curb, and moisten or wash away the ground immediately beneath, enabling the tubbing to sink steadily under the weight of walling building up inside it, augmented if necessary by additional loading on the top of the tubbing. At intervals in the height of the tubbing are provided internal hollow belts, perforated with holes for discharging jets of water into the sinking as the tubbing goes down. By this

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means the sand or mud at the bottom of the tubbing, or subsequently forced up inside it by external pressure, is kept wet enough to be excavated either by pumping or by endless-band bucket-elevators. The same plan is suggested for sinking piers for the foundations of quay walls, without the aid of compressed air, and in lieu of driving piles. Here the tubbing itself, together with the perforated bottom-curb and internal hollow belts, will be of rectangular form; and when each pier is completed by filling up the inside of the tubbing with a solid mass of concrete, the space intervening between two successive piers will be enclosed by sheet piling, constructed of concrete and sunk in the same way by aid of a perforated water-sole; the longitudinal caisson so formed will then be filled up solid, either with concrete or with masonry.

A. B.

A Proposed New Type of Masonry Dam.

G. L. Dillman, M. Amer. Soc. C.E.

(Proceedings of the American Society of Civil Engineers, April, 1902, p. 328.)

The Author points out that although the stability of a dam built to a uniform type of section, is ensured if properly designed and executed, yet the uniformity of section is not necessary to stability; he proceeds to state that a more stable and economical dam can be built in the form of a buttressed wall properly proportioned. The proposed type may be considered as a series of short arched dams between suitably shaped piers. He emphasises the point that it is only necessary to make a water-tight surface and build the remainder of the structure to support it, and argues that in the form of dam proposed any leakage would escape without exerting a dangerous upward pressure.

The Author makes a computation to illustrate this method of design, assuming that the arches between the buttresses are parabolical in horizontal section, thus introducing the strongest arch to support the pressure; he takes the upstream face of the arches vertical, but the corresponding face of the buttresses slightly battered, and their outer profile a straight line at an angle of 45°.

In the resulting design the centre of pressure in the buttresses, with the reservoir full, comes well inside the middle third of the base, but with the reservoir empty the resultant strikes the base nearer to the inner toe than one-third its breadth. The resulting volume of the masonry works out less than in the case of a uniform cross-section, and the maximum pressures are not very materially different in the two cases for a considerable range in height.

A. W. B.

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Apparatus for the Sterilization of Water. GEORGES CAYE.

(La Nature, 19 July, 1902, p. 97.)

All authorities are of accord as to the importance of freeing potable waters from disease germs, and no other plan of effecting this is so efficacious as boiling the water for a sufficient length of time or under pressure. Water thus treated is, however, found to have parted with many of the properties which render it palatable, and it has lost the greater part of the gases which it previously contained, and this causes it to be mawkish and indigestible. An apparatus, devised by Professor Vaillard and Mr. Desmaroux, is here described and illustrated, which makes use of heat for the sterilization of water, but which retains in the water under treatment those qualities that render it desirable for drinking purposes. The apparatus in question can be made in various sizes; the one here described is of a type which has been supplied to the Polytechnic School of Paris and to the Military School of St. Cyr, and is capable of yielding 220 gallons per hour. The principle employed is to heat up progressively small volumes of the water under treatment, and at the same time to cool an equivalent bulk of the water so treated. This is effected by first boiling the water in a heating vessel, the supply to which is automatically regulated, and causing the heated water to pass through a special double spiral worm formed of thin metal plates, the feed water and the boiled water being circulated through the spiral worms in opposite directions; the boiled water parting with its heat to the feed water. This worm has a very extensive surface—about 1,076 square feet—for the exchange of heat, and is arranged in two similar cylindrical chambers. A third chamber is subsequently traversed by the water to retain calcareous deposits which may not have been deposited in the boiler tubes. Owing to the fact that the entire process of heating and cooling has been conducted in closed vessels and without access of air, it is found that the water after treatment retains the chief part of its gaseous contents and its mineral salts, and it is therefore pleasant for drinking purposes. It issues from the apparatus perfectly cooled and fit for immediate use. It is stated that two of the French war-vessels, the "Calédonien" and the "Couronne," have been supplied with this apparatus, which has worked satisfactorily in each case.

G. R. R.

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The Pollution of Public Watercourses in Berlin. SCHÜMANN.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, vol. xxxiv., p. 226.)

Allusion is made to the vast extent to which the water in the vicinity of Berlin, available for public use has, during recent years, become polluted, and the Author states that it seems desirable to ascertain, apart from æsthetical considerations, and merely from the point of view of hygiene, the principal causes of this pollution, and the means which may be suggested to remedy the evil. It is shown that the decision arrived at, in accordance with the scheme of Hobrecht, in 1873, to deal with the Berlin sewage under the twelve radial districts has been somewhat extended by the inclusion of separate systems of drainage for Charlottenburg and Rixdorf, and that all of the radial areas originally laid down have been completed with the sole exception of No. 11, which includes a district so sparingly built over that it still remains to be sewered. The plans of Hobrecht involved a combined system of dealing with the sewage and the rainfall, and the basis of the calculations of the volumes to be dealt with and the total bulk of the sewage are here given. By reference to a block-plan, the Author explains the scheme and its various extensions. Over a large area outside the radial systems it may be assumed that all the domestic waste waters and the factory water find their way into the Spree. Another sensible factor in the river-pollution is the increasing barge-traffic, in which 2,951 persons were found to be engaged on 1 December, 1900, where a census was taken over 19 miles of the river. It is shown that in the period from 1885 to 1899 the area of streets covered with various impervious materials rose from 30·6 per cent. to 82·8 per cent. of the entire road-surface, and this has mainly contributed to a great change in the character of the sewage-water during heavy rainfall. Diagrams are given to indicate the number of times on which the storm-overflows came into operation, and the depth of rainfall needed to set in action these overflows. The volume of sewage per second for various rainfalls is also calculated and the relative volume of sewage attributable to ascertained areas. The state of the various canals connected with the Spree is discussed. Certain of these waterways are seriously obstructed by mudbanks. In many cases these canals are used as receptacles for the snow removed from the roadways during severe snowstorms, and the Author estimates that the solid residue from this source may amount to from 8 per cent. to 10 per cent. of the bulk of snow. A Table is given showing the relative volume of the river water to the population in the case of a number of towns of large size, and here Berlin occupies a very unfavourable position. In conclusion the Author calls attention to the urgent need of a properly constituted authority to investigate the various sources of pollution, and to take measures for their abatement throughout the entire area under review. G. R. R.

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Experiments on the After-Treatment of the Frankfurt Sewage Effluent. Prof. Dr. FREUND and H. UHLFELDER.

(Deutsche Vierteljahrschrift für öffentliche Gesundheitspflege, vol. xxxiv., p. 294.)

The Sewage Clarification Works of Frankfurt, which have been in operation since 1887,[1] consist of four tanks, in which a precipitation process is carried out by the employment of sulphate of alumina and lime. Owing to the growth of the population, and to the extension of the municipal area, it became necessary to enlarge the works, which would, however, have been a very costly matter, and before going to this expense it was decided to undertake a series of experiments with filters, on which the clarified effluent might receive special treatment. It was proposed that such treatment should partake of a chemical and a biological character. A sum of £400 was voted for these experimental works, and provision was made for the cost of carrying on a variety of tests. Plans and sections are given of the series of filters which were constructed for this purpose. These filters were four in number, each of them 11·48 feet square. The first of these beds served as a preliminary straining filter, and contained layers of filtering materials 31·5 inches in depth, viz., 19·68 inches of gravel, 7·87 inches of sand, and 3·93 inches of wood-wool on the top. The three other beds formed the main filter; they could each of them be worked separately, and two of them contained a layer of coke 39·37 inches in depth carefully broken into pieces of the size of a walnut, and evenly distributed; the third coke filter, which was, however, not used, had layers of soft limestone, broken into small pieces interstratified in two places in thicknesses of 2 inches. It was intended to carry out some other trials with this filter, but this was found to be unnecessary. The sewage water employed for these experiments was not subjected to chemical treatment, but was merely allowed to subside in the tanks and the effluent was pumped on to the filter-beds. The trials extended over a period of twelve months, and were conducted only during the daytime, as the night flow of the sewage was sufficiently clear to obviate the need of any further filtration. Tables are given to show the effect of precipitation alone, as contrasted with mere subsidence and subsequent filtration. In all cases both chemical and bacteriological tests were made. By reference to a series of graphic diagrams, the Authors indicate the results obtained, and they adduce algebraical formulas by the use of which calculations may be made for various volumes and degrees of pollution. They are thus able to indicate the relative degrees of purification effected by each cubic metre of filter. In the same way, they deal with the question of the cost of treatment, and they state

[1] Minutes of Proceedings Inst. C.E., vol. lxxix. p. 410.

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that each 100 gallons of daily sewage-flow cost 1·98*d.* per annum for this treatment, which is thus a relatively expensive one. They conclude, however, that for certain towns, situated at a distance from water-courses of large volumes, or in narrow valleys, this mode of dealing with the sewage will be found to be advantageous.

G. R. R.

Separate System of Sewerage, with Limited Introduction of Rain-Water. J. G. RICHERT.

(Gesundheits-Ingenieur, 15 May, 1902, p. 137.)

The Author defines a combined water-carriage system as one which removes the whole of the rainfall, together with the domestic and surface water. The sewers on the separate system are arranged to deal with the domestic soiled water alone, as distinct from the surface water, though in some cases a certain volume of the rain water falling on the roofs and courtyards enters the house drains. The combined system is the best, but, at the same time, the most costly method of drainage, as it entails the provision of sewers capable of dealing with the entire rainfall, which may at times amount to fifty times the volume of the domestic waste-water or sewage proper. An account is given, together with diagrams, of a plan of keeping the water reaching the gutters of the roadways in separate drains, and of so constructing the gullies as to allow only a small proportion of the rainfall to enter the foul-water drains for flushing purposes. This is effected by making two orifices to the gullies, which are divided by a partition; a small low-level exit leading to the sewer, and a larger exit-pipe, near the surface, leading to the rain-water drain, and only coming into operation at periods of heavy rainfall. By means of diagrams the Author explains this system, and shows that one great advantage it possesses is that it is impossible for the foul-water sewers to become surcharged, and thus for the sewage to be forced back into the basements of the houses. Screens are in all cases provided in the gullies, which prevent the suspended matters in the surface water from reaching the foul-water drains. It is pointed out that, under this plan, each regulating-gully becomes a species of storm-overflow, but its operation is to discharge the excess of water into the river, unmixed with sewage matters, as in the case of the ordinary storm-overflow. The amount of rain-water admitted to the sewers can, under the Author's system, be regulated to a nicety, while the provision for the rainfall is practically unlimited, as the bulk of the rain-water flows away in open channels or in special surface drains of large size.

G. R. R.

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Action of Ethyl Alcohol on Micro-Organisms. GERMUND WIRGIN.

(Zeitschrift für Hygiene, vol. xl., 1902, p. 307.)

Various writers have discussed the action of alcohol, both in its pure state and also in different degrees of dilution, up to 25 per cent., upon bacteria, and the Author considered it might be of use if he carried out a series of tests in which still more dilute solutions, below 10 per cent., were employed. In small quantities alcohol, as it is well known, enters into the composition of many important articles of food, and it is generally considered to have a preserving influence. Not a few micro-organisms, however, give rise spontaneously to the production of alcohol in greater or lesser quantities, and though very minute percentages of alcohol undoubtedly exert a deleterious effect on the development of certain bacteria, they appear to be of advantage to the growth of others. The present enquiry deals with all these various facts, and the Author has likewise investigated the action of alcohol in worts and beer.

The method in which the dilute solutions were prepared, and the composition of the nutritive solution, is fully explained. Great difficulty was experienced in preventing the evaporation of the spirit during the period of testing, and in open vessels the loss of alcohol was so extensive that in some cases a 10 per cent. solution was reduced while under test to 8 per cent. By the use of india-rubber stoppers, however, for the glass cylinders the loss of alcohol was reduced to a minimum. A complete list is given of the micro-organisms which were used as tests, and which included the bacilli of anthrax, typhoid fever, diphtheria, and also a variety of non-pathogenic organisms. In his general conclusions the Author states that alcohol in all degrees of dilution has a distinctly deleterious action upon the development of nearly all kinds of bacteria, and retarded or, in some cases, wholly prevented the formation of spores. Certain bacteria, as, for instance, those of vinegar, are, however, favoured by the presence of from 5 per cent. to 7 per cent. of alcohol.

G. R. R.

Artificial Ice Manufacture at Paris. GEORGES CAYE.

(La Nature, 9 August, 1902, p. 147.)

The ice in common use is often obtained from highly contaminated sources, and in order to prepare ice which shall satisfy all the requirements of sanitary science, works on a large scale, capable of producing 50,000 tons annually, have recently been erected at Billancourt, near Paris. The water employed in the manufacture is drawn by mammoth pumps, which act by compressed

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air without valves of any kind, from a depth of 164 feet, and it is in the first instance stored in a large tank beneath the works. It is freed from its mineral salts in a Desrumeaux purifier, capable of treating 132,000 gallons in 24 hours, and is afterwards vaporized in special boilers and filtered through coke. The freezing takes place in a vast chamber which contains the vats. The walls and floors of this chamber are constructed in such a way as to avoid all changes of temperature, with two special air-spaces in the hollow walls and four thicknesses of boarding covered with insulating material. The vats contain a saline liquid which will not readily freeze, and each vat is constructed to take 4,000 moulds. The contents of the vat are cooled by pipes charged with liquid compressed ammonia, about 15 miles of pipes being distributed in each vat. By this means the liquid in the vats is reduced to a temperature of 10° C. below zero. The moulds are filled automatically and remain in the vats for 60 hours. The block of ice yielded by each mould weighs about 308 lbs. The ice stores will hold 10,000 tons of ice. The ammonia is re-compressed to a liquid, after it has expanded into the gaseous form, by engines of 400 HP., and there are five boilers with a total of 1,200 HP. to furnish the steam-supply for the factory. The output of the works is at present 360 tons of ice per diem, but it is being raised to 500 tons by additions to the plant. Illustrations are given of the machinery and of the ice-cellars.

G. R. R.

Lighting Creek Street Tunnel, Brisbane. W. S. Cottew.

(Proceedings of the Queensland Institute of Engineers, 1901.)

The Author describes in this Paper the present system of electric lighting used in the railway tunnel running from Creek Street, at the Central Station, Brisbane, towards Brunswick Street in the valley.

The tunnel is 880 yards long, and the average time taken by a train in passing through is one minute. When the tunnel was first opened, in 1890, the carriages were lighted by lamps burning Chinese oil, and in the daytime these lamps were taken out of an "up" train and put into a "down" train; afterwards the Pintsch system of oil-gas lighting was adopted, and the lights were turned down in the daytime, except when the train was actually in the tunnel. This system, however, proved too expensive, and it was recently decided to light the tunnel during the daytime instead of the carriages.

A trial was first made with gas-lighting, but it proved unsatisfactory owing to the excessive draught, and it was decided to adopt 160 32-candle-power electric lamps, half upon each side of the tunnel at a height of 7 feet from the rail. The height was

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proved best after careful experiment; brilliant illumination was not desired, but sufficient to render passengers visible to each other.

Current from the Tramway Company was to be used for lighting the suburban stations from Eagle Junction to Indooroopilly, so the same current was adopted for the tunnel. The potential of supply is 550 volts, and the lamps in the tunnel are used five in series; one single-pole switch controls all the lamps, and at first it was turned on by hand at 5.30 a.m. and off at 5.30 p.m., the daily consumption being 211 B.T.U. The actual time occupied by trains in transit through the tunnel is only 2 hours and 1 minute between the times named, it was therefore obvious that a great saving could be effected if the light could be automatically switched off in a similar manner. The Author designed the special apparatus which is now in successful use; diagrams and reproductions of photographs accompany the original Paper which show the details of the apparatus. The chief features are solenoids, which move a switch provided with mercury cups, one pair of solenoids closing the switch and another pair opening it. The inner cups are of wood and the outer of cast iron. The cups contain mercury to a depth of $\frac{1}{8}$ inch, covered with paraffin (*sic*) oil to a depth of 2 inches. A very powerful magnetic field is produced in the neighbourhood of the cups, and this acts as a magnetic blow-out, and there is a complete absence of sparking, although a current of 32 amperes at 550 volts is broken, and it has proved so successful that the mercury has not been renewed for nine months, during which the apparatus has been at work.

Each passing train makes a contact through an insulated rail, which closes the circuit of a battery of 24 Leclanché cells, which actuate relays, and these in turn control the main solenoids, so closing the switch. A saving of £600 per annum has been effected by the use of the apparatus.

E. R. D.

Wood Paving. G. PINKENBURG.

(Zeitschrift für Bauwesen, 1902, p. 419 *et seq.*)

The Author divides his subject into six parts—(1) a historical sketch of the development of wood paving; (2) discussion of the materials used—gravel, cement, wood, etc.; (3) concrete foundations and cement covering, etc.; (4) maintenance; (5) cost and contracts; (6) duration, advantages and disadvantages.

The Author begins with a historical sketch of the progress of wood-paving from the time of its first introduction into London in 1839, citing the classic work of Petsche "Le bois et ses applications au pavage." He then proceeds to lay down the conditions which govern the successful application of wood to roads, and to draw attention to the manner in which the structure of the fibres, the

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quantity of albumen in the cells, and the capacity for absorbing water, affect the selection and durability of the wood. The requisite qualities, viz., elasticity, the capacity to spread over without breaking, small amount of albumen and small absorptive capacity for water under suitable conditions, are admirably combined in the Coniferæ. The Author compares these woods with beech, and illustrates with figures the different manner in which they wear under traffic, referring incidentally to the harder woods from Australia and tropical countries. The Author next discusses the form of cross-section. The conditions which affect the form of the road are its width, the longitudinal slope, and the presence or absence of tramway lines, which force the heavy traffic to the sides and require them to be made flatter. He points out that the parabola is a curve which may be made to adapt itself readily to the conditions required, and recommends engineers and contractors to apply it in a scientific manner to fulfil the end in view. Thus the maximum slope of a road being compounded of the longitudinal slope with the slope of the cross-section, the rise of the parabola must be lessened in proportion as the longitudinal slope increases, and the Author illustrates this by working out an example.

In Berlin the usual practice in laying the concrete bed is to mix the concrete dry on a wooden floor in the proportion 1 gravel to 1 cement until the whole has a uniform colour. Water is then added, and the mass worked into a stiff compound, which is spread upon the ground to a minimum thickness of 15 centimetres (6 inches), increasing to 20 centimetres (8 inches), according to the traffic and the nature of the ground. Since the concrete bed is the basis of strength and durability for the whole structure, it is false economy to cut down the thickness, but experience shows that 20 centimetres (8 inches) is sufficient for the heaviest traffic. Whilst the concrete is setting, the wood-blocks are sorted into piles, with reference to their quality, so that pieces of equal hardness, etc., shall be placed together. The rows are laid either perpendicular or inclined to the direction of the street, the diagonal system being adopted for the slopes of all bridge approaches in Berlin, because this arrangement protects the joists from the injury caused by horses, which, in resting, strike their hoofs forcibly into the joints. For this reason also the heart-wood should be laid towards the crown of the bridge. The joints, which were formerly specified by French engineers to be 1 centimetre wide, are now reduced to 6 and 8 millimetres ($\frac{1}{4}$ inch). Thin grouting, 1 cement to 2 sand, is run into these. The method of overcoming the difficulties due to expansion of the wood are explained, and the Author concludes by drawing attention to the importance of proper maintenance, immediate attention to holes, to the condition of the clay joints, and to cleanliness, since the removal of organic bodies which cause decay is essential to the longevity of the wood. The price per square metre in Berlin is estimated at about 17 marks, the paving to be kept in order by the

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contractor for 3 years from the date of taking over. After this it is usual to make a new contract for a further 3 years.

As regards the objection to wood paving that it forms a breeding-ground for bacteria of all kinds, the Author points out that if this were the case the health of Paris and London would be seriously affected.

E. H. S.

Report upon the Collapse of a Building in Basel.

(Schweizerische Bauzeitung, 1902, p. 213. Figs.)

The city surveyor, A. Gieser, and Professors Ritter and Schüle were appointed to report upon the collapse of a building, which occurred on the 28th August, 1901, in the suburb of Aeschen, near Basel. The inspection of the site by the committee was made on the 30th and 31st August; the building works had been undertaken by the Basler Baugesellschaft; and the erection was known as the Bear Hotel; the area covered was 152 feet deep with a frontage of 59 feet. The façade and party-walls were of brickwork, but the interior walls, floors, and roof of the Hennebique construction. The builder stated that the strains were calculated and the plans for the Hennebique work were prepared by the Hennebique firm in Paris. At the time of the catastrophe the building was completed in carcase, and the accident seems in many respects to have resembled that which took place some years ago in Victoria Street, Westminster. The committee thought that sufficient care had not been used in the mixing of the concrete, and that the wood centreing had been removed before the materials had been properly set. The back part of the building stood satisfactorily, and the work seemed to have been carried out with care.

Tests of the concrete and evidence proved that the aggregate consisted of a mixture of gravel and sand dug out of the foundations, and this contained some loam, which was not washed out. The experts point out that owing to the desire for rapid completion of the building the centreing was removed too early, and the full load brought upon the concrete and metal columns before they were properly hardened. Laboratory tests of the materials of construction were made with the following results:—the steel and cement were both of good quality, but the aggregate contained too much fine sand and too few stones of fair size; also it was not clean. The general result was, that the concrete had only about half the tensile strength which it would have had if the aggregate had been clean and of suitable quality.

E. R. D.

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The adoption of Metallic Returns for the Telephone Service in Upper Silesia. WIEGELMESSER.

(Archiv für Post und Telegraphie, 1902, p. 33.)

At the south-eastern corner of the German Empire, where Germany, Russia, and Austria-Hungary join, there is an important industrial district containing the towns of Tarnowitz, Gleiwitz, and Myslowitz, with an area of about 142 square miles. The Author then gives a list of the various industrial concerns, from which it appears that about 166,000 HP. are in use. A telephone exchange was founded in 1883, with sixty-four subscribers, and the number had so increased by 1899 that the underground and aerial lines along the roads to Kattowitz would no longer suffice. Recently, considerable annoyance had been caused by induction due to the working of electric railways in the neighbourhood. Good earth-returns could no longer be obtained, owing to the sinking of the ground-water-level caused by mining operations. The insulation of the overhead lines was also very difficult to maintain, owing to the dust, smoke, and rain; it was therefore decided to adopt the system of metallic returns throughout, and the work was deputed by the Post-Office authorities to the staff at Oppeln. In 1899 there were eleven double and thirty-nine single trunk-lines, and 802 subscribers' single lines; and up to June, 1900, the cost of replacing these lines had reached to £12,548 for trunk-lines, and £16,563 for subscribers' lines, and about 1,101 subscribers connected in all. The Author then gives full details of the particular sizes of the multiple cables, and of the cost of the same. Some of the work has been carried out overhead, but a very large part has been put underground; the working of telephones in the district had been practically impossible owing to the vast increase in the use of high-potential services for power-transmission. The new service has proved very satisfactory.

E. R. D.

The Strength of Spherical Surfaces under External Pressure. C. BACH.

(Zeitschrift des Vereines deutscher Ingenieure, 1902, p. 333.)

The strength of circular cylindrical or spherical surfaces against external pressure is not amenable to calculation in the same way as when the pressure is internal. The question is in most cases one of stability, from the liability of the circular or cylindrical plate to collapse. Brewing coppers and other similar vessels present a case of this kind, and the Author, in order to arrive at a working rule for the thickness of plate, carried out a series of experiments on ten copper bottoms hammered to the form

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of a spherical segment, and, after being riveted inside a circular cylinder, were subjected to the pressure of steam admitted into the cylinder. Careful measurements were made of the deflections of the copper plate at 32 points and the pressure was increased gradually until the plate collapsed. The results of the experiments are contained in the Paper. In some cases the plates were turned inside out by the pressure. Bars of copper were tested for strength and elastic properties. The stretch coefficient was found to be about $\frac{1}{1800000}$ per kilogram per square centimetre ($\frac{1}{7620}$ per ton per square inch). The point at which the stress strain diagram bends sharply over was at 1,800 kilograms per square centimetre (11·43 tons per square inch), the ultimate tensile strength being 2,347 kilograms per square centimetre (15 tons per square inch). The ultimate extension on 8 inches and the contraction at fracture were respectively 21 per cent. and 45 per cent.

Putting p_c for the steam pressure at the collapse of the copper vessel, r for the radius of the spherical segment, and s for the thickness of the copper, the Author calculates the stress on the copper on the supposition that it is in the form of a complete sphere. Calling this k_c he finds that it can be expressed with considerable accuracy by the following formula :—

$$k_c = 2{,}550 - 120\sqrt{\frac{r}{s}} \quad \cdots \quad (1)$$

k_c is in kilograms per square centimetre.

For tons per square inch—

$$k_c = 16{\cdot}45 - 0{\cdot}774\sqrt{\frac{r}{s}} \quad \cdots \quad (1)$$

The practical rule the Author arrives at is that so long as the radius of the segment is greater than 167 times the thickness of the metal, this thickness may be calculated on the supposition that the segment forms part of a complete sphere subjected to pressure, allowing a stress of from 300 kilograms to 400 kilograms per square centimetre (1·9 tons to 2·5 tons per square inch). When the thickness becomes less in proportion to the radius of the segment, the safe stress is to be calculated at from three-tenths to four-tenths of k_c, which is to be obtained from equation (1).

For spherical segments of mild steel subjected to external pressure, the Author considers the safe stress to be from 400 kilograms to 600 kilograms per square centimetre (2·5 tons to 3·8 tons per square inch), while it should not in any case exceed from 0·25 k_c to 0·35 k_c, k_c being the collapsing stress. The collapsing stress is in kilograms per square centimetre—

$$k_c = 2{,}600 - 115\sqrt{\frac{r}{s}}$$

The Author also considers shortly the strength of boiler furnace tubes. J. G.

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A Uniform System of Testing Wood. Prof. M. Rudeloff.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1901, p. 270 *et seq.*)

In the *Mittheilungen* for 1899, p. 180, the Author drew attention to a number of circumstances which may affect the results of experiments on the strength of wood. Amongst these were, the rate of application of the load; and in compression, the manner of preparing the ends, and the proportions of the test-pieces.

The object of the present experiments was to determine how far these factors affect the results, and to offer definite suggestions for a uniform system. The investigation was made upon specimens of pine, white beech and oak, dried in the air. Tables and curves of the results are given, and the measuring apparatus used is described and illustrated.

The Author sums up his results by recommending that 1. The compressive tests for strength shall, in general, be made on cubes. 2. Compressive tests with elastic measurements shall be made on prisms having a square cross-section, and a length three times that of the edge of the cross-section, the prisms to be cut so that the two sides shall be as nearly as possible tangential to the annual rings, and the compression to be measured separately on each pair of faces, and if possible at the same time on the same piece. The lengths on which the measurements are made to be approximately equal to the edge of the cross-section (one-third the length of the prism) and symmetrically placed with respect to the centre of the prism. 3. The ends of the test-pieces either to be prepared with the plane, or carefully cut with a saw. 4. The rate of application of the load in the case of compression experiments, as well as in bending tests, to be so chosen that the load increases by 20 kilograms per square centimetre (284·5 lbs. per square inch) per minute.

E. H. S.

The Testing of Leather for Industrial Purposes.

Henri Boulanger.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, April 30, 1902, p. 491 *et seq.*)

As the result of certain investigations into the strength of different samples of leather, the Author found that little information was available respecting the actual effects of the various substances used for tanning purposes upon the tensile strength of this material, and that nothing was known respecting the resistance to tensile strain, nor as to the elasticity of the so-called "green leather" (raw hide), now largely used for gearing, exposed

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to frequent shocks. The Author, therefore, undertook a series of tests with a Delaloé 10-ton machine upon strips of leather cut from the hide, and also formed into belting in single, double, and triple thicknesses. He used native ox-hides tanned with oak bark, the same hides chrome-tanned, and foreign buffalo hides tanned with chromic acid. By means of photographs the method of obtaining test-pieces in different parts of the hide is explained, and graphic diagrams indicate the results of the various tests, which were all conducted with strips of a uniform size: 15·74 inches long by 2·75 inches wide at the jaws and 1·97 inch wide at the neck. The reduced width extended for 7·87 inches in length, and all elongation was reckoned on this part of the strip. It was decided in all cases to expose the test-piece to a strain of 447 lbs. for each inch in width, and to ascertain the permanent elongation due to this load, after its removal, then to test the sample to rupture, indicating the progressive elongation as the load was increased. After all the samples from one hide had been tested, the test-pieces were re-inserted into the spaces from which they had been cut, and the hide was again photographed. Tables are given of the complete series of tests and photographs of certain of the strips with characteristic fractures. Tests were also conducted with belting sewn in different ways and with various kinds of stitching and lacing-up to form joints, also with rivets and metal fastenings, eyelets, etc., and with glued or cemented joints. All varieties of stitching together leather in thicknesses to form belting were also tested, and the results of the tests are set forth in Tables, and explained by graphic diagrams. The Author gives also a series of tearing tests, which were carried out by slitting up a strap in the direction of its length for a few inches and then splitting the two ends apart. In all cases the results of the tests are photographed, and the figures are given in Tables. Identical experiments were carried out with hides tanned with chromic acid, and with raw hides, and all the results are set out in diagrams and Tables.

G. R. R.

Repetition Experiments with Seamless Steel Cylinders for containing Carbonic-Acid Gas. Prof. A. MARTENS.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1901, p. 217 *et seq.*)

This report forms a further contribution to the subject of the strength of cylinders for the storage of high-pressure gases, the "Results of Experiments with burst iron cylinders used for storing hydrogen," having been published in the *Mittheilungen*, 1896, p. 2.

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in Laar bei Ruhrort having decided to make repetition tests on seamless steel cylinders, nine of these were cast at the same time, full particulars of which as to dimensions and weight are given, with illustrations and explanation of the method of applying the pressure and measuring the deformations produced, with sketches of the fractures.

One of the cylinders was used to determine the properties of the material in its initial condition, specimens which had been heated to redness and chilled being tested both in tension and by bending. A second cylinder was strained to the elastic limit by internal pressure, then cut up and tested as in the case of the first cylinder. Cylinder 3 was strained to rupture and the material tested as in the previous cases. From the results obtained the changes could then be deduced, which the material had experienced in the preceding case when permanently strained.

Cylinders 4 to 9 were subjected to repetition tests, the pressure being made to vary between zero and an upper limit, and repeated until fracture occurred, or up to 2,000 applications. To test the effect of this treatment on the material, test-pieces were then cut from the fractured cylinders and tested as before.

The experiments showed that the effect of annealing the cylinders was to cause the strained material to return almost to its original condition. They also confirm in a striking manner the value of the ratio of the elastic limit to the breaking stress as a test of the condition of a material, especially of the mechanical treatment it has undergone in a cold state; they show also how by strain the material suffers in its capacity to undergo further change of form.

The breaking stresses obtained in the repetition tests are plotted, and the curve drawn through them illustrates the general law that the greater the range of stress, the less the number of applications requisite to produce fracture. A larger number of tests being made this curve could be more accurately determined, and, by means of it the stress could be predicated, under which the material would fracture only after an infinite number of applications of the load.

The Author further points out that should the expectation be confirmed, that fracture will not take place under stresses which cause no additional permanent strain, there will be a simple practical test for avoiding the danger of sudden bursting in service, namely, by weighing the cylinders full of water, before and after testing, and discarding all those which by additional weight, show an increase in volume.

The experimental results are elaborately tabulated and illustrated by curves.

E. H. S.

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Experiments on the Stability of a Partition Wall. K. Stigler.

(Zeitschrift des österreichischen Ingenieur- und Architecken-Vereines, vol. liv., p. 351.)

To gain some idea of the distribution of pressure in partition walls, tied at each end, the Author constructed such a wall, 5·9 inches (15 centimetres) thick, 17·3 feet (5·28 metres) long, and 12·3 feet (3·75 metres) high, the wall itself being laid on a beam, supported by wedges, to facilitate fall during the test. After leaving four months, for the mortar to set hard, the supports were loosened, whereupon a sinking was observed, extending for a length of 8·36 feet (2·55 metres) at a level of 6·85 feet (2·09 metres) above the beam, the remainder of the wall above this level remaining intact, as was also the case with two bracket-shaped portions at the ends—a large bracket at the end where the ties extended right down to the floor, and a smaller bracket at the other end where the lower ties were absent. On the removal of the beam, the settled portions subsided, leaving the upper portion standing, as though composed of two independent brackets and a wedge-shaped piece resting thereon by abutments of 45°. To confirm this view, one end of the remaining portion was propped, and demolition commenced by taking out the bricks above the larger bracket, beginning at the top. No cracks in the propped part were noticeable until the support on the bracket side had been reduced to four courses, extending an average of 23·6 inches (60 centimetres) from the bracket; and subsidence took place only on the last brick of these courses being withdrawn.

In the Author's opinion the pressure on the foundation is confined to the portion of the wall concerned in the first subsidence, *i.e.*, about one-third the total weight, the remainder of the pressure being distributed on to the end walls by means of the ties.

C. S.

Cement Pipes with Reinforced Walls. Max Moeller.

(Deutsche Bauzeitung, vol. xxxvi., 1902, p. 157.)

Finding that concrete pipes subjected to pressure on the crown —*e.g.*, when used for railway culverts, etc.—tend to fracture in the centre of the crown, at a vertically opposite point in the base, and at points midway between the two, the Author proposes to reinforce such pipes by strengthening the weakest points and inserting embedded iron, set near the inner surface at the top and bottom, and near the outer surface at each side. Pipes constructed in this manner, measuring 29·52 inches (75 centimetres) in length, 39·37 inches (100 centimetres) in internal diameter, with walls 5·42 inches (138 millimetres) thick at the strengthened parts, and reinforced with

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iron of a sectional area of 1·085 square inches (7 square centimetres), are found to possess a breaking strain of 32,628 lbs. (14,800 kilometres), which is equal to a load of 43,430 lbs. (19,700 kilometres) per running metre (39·37 inches). In applying the load, an iron bar, 0·78 × 0·78 inch (2 × 2 centimetres), was laid along the crown of the pipe and surmounted by four beams, supported at one end by a narrow iron bar, but free at the other. On these beams were placed the iron pigs forming the load, so arranged that only one-sixteenth rested on the end support, and a cross timber was inserted through the pipes, to prevent total collapse on breaking.

The resistance of the pipes to top pressure is increased two- to three-fold by embedding them in rammed earth, provided the ramming be properly performed.

The Paper is illustrated with diagrams, and a block showing the method of applying the load test.

C. S.

Glass Bricks.

(Mittheilungen über Gegenstände des Artillerie- und Genie-wesens, 1902, p. 510 *et seq.*)

This article is a report of the "Technisches-Militär-Comité" on a new invention, which consists of hollow glass bricks for use in walls and roofs. These bricks are made in different forms and sizes, illustrations with dimensions being given in Plate 30, and the prices and weights in tabular form on p. 514.

These bricks are shown to be very inferior in strength to wire-woven glass (drahtglas)[1] as regards their resistance to blows and shocks, as well as to penetration by mechanical means. Their high resistance to the action of fire is referred to in the *Oesterreichischen Wochenschrift für den öffentlichen Baudienst*, (1902, Pt. 4), glass bricks, with suitably faceted surfaces surrounded by a wire web, being practically indestructible up to their melting-point. It is here suggested, however, that, in consequence of the possibility of initial strain in the glass, destruction may occur through exceptional changes of temperature.

The sides of the bricks are so formed that the direct sunlight is broken up and scattered, so as to distribute it better than is the case with ordinary windows. On account of their embossed and figured surface the bricks are merely translucent, and no view through the glass can be obtained. The enclosed air is an excellent non-conductor of heat, and a preventive of noise, moisture, and electrical discharges, and no sweating or dripping occurs even with considerable difference of temperature between the air inside and out.

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[1] Mittheilungen über Gegenstände des Artillerie- und Genie-wesens, 1899, p. 852.

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Roofs, domes or skylights of small size built with these bricks require no ironwork, whilst those of larger span need only a simple and cheap framework. The bricks are laid in a similar way to ordinary bricks, with a mortar consisting of one part Portland cement, two to three parts fine sharp sand, and ¼ lime mixed not too thin with water. Neat Portland cement increases too much in volume on drying, and dangerous strains in the glass are caused thereby.

These bricks appear to be specially applicable to partition walls required to transmit light, and for subdividing large rooms which have the light on one side only; to workshops, studios, laboratories, etc., where the work is distributed over the whole space, and a more or less uniform light is essential. They are also suitable for obtaining light through party walls which adjoin neighbouring property. Their application to roofs, domes, etc., however cannot be recommended, as the strength of such structures is indeterminate.

E. H. S.

Wire Glass. L. APPERT.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 30 June, 1902, p. 745.)

It is pointed out that wire glass or "armoured glass" presents many analogies with armoured concrete, or concrete in which a metal core has been embedded, and glass having a metal inlay or skeleton acquires a degree of toughness and cohesive strength far in excess of that found to exist in ordinary glass. The Author gives an outline of the process of making ordinary sheet glass, and then proceeds to deal historically with the numerous inventions relating to the insertion in various ways into glass of metal inlays or cores, by which means the strength of this material is doubled and in some cases tripled. Even when submitted to high temperatures and in contact with water, wire glass has, at actual fires, been proved to be extraordinarily tough and resistant, and by recent improvements it is possible to introduce wire meshwork or trellis into sheet glass without interfering very materially with its transparency. The metal most suitable for this purpose is fully discussed, and though nickel steel with 34 per cent. of nickel has exactly the same coefficient of expansion as glass, it has been proved that the tendency of this alloy to emit large volumes of gas (amounting to treble its volume) when coming into contact with the molten glass and its high cost, does not justify its employment. The most suitable material is stated to be polished steel wire of the same character as that used for piano strings. Such wire may with advantage be slightly tinned before use, but other methods of preparing the wire are discussed. The first patent for wire glass dates back to 1855, and since then ten patents for modifications of the process of manufacture have been secured in France,

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twenty in Germany, twenty-two in this country, and thirty-five in the United States. The Author briefly describes the various systems of manufacture and illustrates the machinery employed. The advantages of the use of this material are set forth in detail and its chief properties are discussed.

G. R. R.

Gas-Engines. D. Clerk.

(Inst. Engineering and Shipbuilders, Trans., vol. xlv., Feb., 1902, pp. 1–43.)

The Author reviews the history of the development of gas-engines, and discusses the principles which have determined their increase in efficiency to the value of 30 per cent. now attainable. He describes various types of oil- and petrol-engines, and the large engines working with blast-furnace gases. Finally, he mentions his own experimental work and the various engines built on the Clerk cycle, with an impulse every revolution; a large number of engines are now being built to use this cycle. He believes that further developments will be on the lines of an impulse per revolution and of compounding. For marine work he thinks a constant-pressure flame engine would be required.

Discussion.—Foulis believed that explosion engines in large units would become too unwieldy, and looked to constant-pressure flame engines for further developments. He described some experiments made by him on continuous ignition of gas-mixtures, and pointed out that the difficulty was to avoid explosion and obtain continuous ignition. Clerk, in reply to several speakers, said that the Diesel engine was wrong in theory, and pointed out the serious danger of explosion in case of a failure to ignite. The advantage of compounding lay, not so much in saving exhaust pressure, as the maximum saving would be 10 per cent. in this, but rather in reducing the weight of the engine, which depended on the ratio of the average and maximum pressures. The Paper contains numerous figures and plates.

G. H. B.

Niel Gas-Engine.

(Génie Civil, vol. xl., 29 March, 1902, pp. 362–363.)

A new gas-engine, constructed by the "Cie. des Moteurs Niel," is described. It is intended for stationary use, and has a single horizontal cylinder working on the Otto cycle. Special attention has been given to the governing, which is effected by controlling the lift of the gas- and air-valves. These valves are mounted one above the other on the same stem, and are normally held against

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their seatings by an external spring. At the top of the valve stem is mounted the piston of an air-dashpot; the ingress of air into the dashpot as its piston descends, with the valve stem, on the admission stroke of the engine, being regulated by a centrifugal governor. The valves are controlled from the admission cam on the cam-shaft by means of a telescopic rod coupled to a bell-crank, one end of which is forked, and engages with a collar on the valve stem. A spring in the telescopic rod holds the roller at its lower end against the cam, and presses the bell-crank fork against the valve-stem collar in opposition to the tendency of the valve spring to hold the valves on their seats. The normal action of the admission cam is to compress the telescopic-rod spring and cause it to overcome the valve springs, so lifting the valves; but if the governor comes into operation, more or less vacuum is created in the dashpot, as the piston on the valve stem descends, and the lift of the valves decreases as the combined pressure of the valve spring and pressure on the dashpot piston become more nearly equal to the downward pressure of the telescope rod, tending to open the valves. The following gas-consumption figures are given:—

	Cubic Metres per HP.-Hour.
Running light	9·64
Half charge, 25·26 HP.	15·147
Full „ 46·02 HP.	20·194

The thermal efficiency works out at 18·8 per cent. on half and 25·5 per cent. on full charge, and the mechanical efficiency at 86 per cent. The normal speed is 216–219 revolutions per minute.

C. R. D'E.

Bardon's Portable Combined Oil-Engine and Dynamo.

(France Automobile, vol. vii., 22 March, 1902, pp. 186–187.)

In this article a detailed description is given of the conditions which have to be fulfilled by a combination of oil-engine and dynamo, so as to be effective, economical, and at the same time portable. In the case described, a 12-HP. four-cylinder vertical engine is coupled direct to a dynamo, and both are fixed on to the same framework. Electrical ignition is employed. The oiling is done automatically. The dynamo used was a four-polar one, and capable of generating 50 amperes at 145 volts pressure and at 980 revolutions per minute. On trials made with that combination for 10 hours and 45 minutes the results obtained were: Current generated 42 amperes, voltage 149; 5, at a speed of 960 revolutions per minute, the power generated was 67, 2 kilowatt-hours, and the total oil consumed was 64 litres. This gives a consumption of 0·951 litre of oil per kilowatt generated, or 0·56 litre per HP.

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Considering the price of oil to be 0·40 franc per litre, the expenditure per HP. comes to 0·225 franc. The sizes made vary from 3 HP. to 12 HP., and the motors are accordingly made with one, two or four cylinders. The dimensions of the combination used in the trial were: length, 2 metres; width, 0·67 metre; and height 1 metre. The total weight was 1,000 kilograms. A side view of the combination is given.

L. G.

Steam Motor-Cars for Railway Service.

(Engineering News, vol. xlvii., 6 February, 1902, pp. 102–105.)

The advantages attaching to the employment of steam motor-cars on branch lines, where ordinarily a 500–800-HP. locomotive is used for conveying, say, about twenty or so passengers, is beyond all question, as under the latter circumstances traffic must be carried on at a dead loss. The steam-motor has advantages possessed by the storage battery, which has for such service been tried and found wanting, and, beside its many faults, is expensive both to establish and maintain. Its radius of action is also very small, cars so equipped being practically closely tethered to the power stations; which same objection applies also to the compressed-air motor and the different kinds of stored steam or superheated-water motors. The trolley and conduit systems have troubles of their own when concerned with the operation of long lines with light traffic, particularly in connection with the heavy cost of road and central station with capacity sufficient to take care of the maximum traffic. The internal combustion motor is at present unsuitable on the score of difficulties met with in starting. Several experimental steam-cars have from time to time been tested in America without leading to any results beyond showing the enormous field which a successful steam-car would open for cheap railway lines. The failure of the cars tested was due to the motor being designed too much on the lines of ordinary locomotive construction; to the cars having too much dead weight; to being designed for too high a speed and with too great a hauling capacity. Steam-motor construction will be successfully developed by copying electric-car construction and utilizing speed-reducing gears placed between the engines and driving axle, while the employment of oil fuel may obviate the existing difficulties in connection with firing. The boiler design is a most cogent factor, and either a miniature Scotch boiler or a water-tube variety would probably meet the case.

The first car dealt with was constructed by the Schenectady Co. An old 60-foot dining-car was taken, and one of the six-wheel trucks removed. This end was then altered for receiving the engine or "steam truck," the interior of the car being partitioned

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off for an engine-room. The vertical boiler (top 5 feet 3 inches, bottom 4 feet 4 inches) was rigidly attached to the trunk or engine frame so that no flexible steam-pipes were required. It was fitted with a Regan water-gate. The storage of water gave rise to trouble, for this being gradually consumed during the trip, it was necessary to arrange the springs so that the car could ride easily with a variation of load of about 12,000 lbs. From running tests it was found, however, that no ordinary application of truck springs would give an easy riding body with the great load variation. The Erie Railroad had a similar car built, the rear end of the car being carried, in this case, by an ordinary four-wheel passenger-car truck. Its use was discontinued because of the jar transmitted from the engine to the passenger end of the car and of the insufficiency of the boiler capacity. The Baldwin steam-car—built for the Cincinnati, Hamilton, and Drayton Railway—had its boiler stationary in relation to the car-body, resting upon the framing of the car, flexible connections being employed. The gear was arranged in the usual way, the special feature being the vertical boiler with a circular fire-box tube and conical smoke-box. Circular rows of 1¼ tube were fitted between the plates, whilst a 10-inch tube passed through the centre, being connected at the top with a coal magazine surrounding the smoke-stack. Around the tube's base were twelve circulating tubes projecting down into the fire-box and guiding the coal to the centre of the grate. This car was withdrawn from service after a few months, the automatic stoking not being a success, whilst the tubes became overheated and the boiler capacity was generally insufficient. Unpleasant vibrations and swaying of the car was caused by the tanks and condensers. Oil fuel was experimented with by way of increasing the steam capacity, but the want of room in the fire-box of these vertical boilers precluded any chance of success. The Baldwin Car Company also built the steam-motor used by the Pittsburg, Cincinnati, Chicago, and St. Louis Railway, with an engine of the Vauclain four-cylinder compound type, valve gear of the Stephenson shifting link pattern, and a vertical boiler of the submerged flue type with a coal magazine round the smoke-stack. Boiler trouble again upset all calculations, the self-feeding arrangements not working properly. The Rowan steam-car, extensively employed, has the engine and car portion separated, with an arrangement by which the front ends of the car-sills would be supported on the engine-frame. In this car the forward end is hinged and can be thrown open to clear the boiler. The steam "dummy" system is still in use on minor street and suburban U.S. railways, but speed is necessarily limited.

C. E. A.

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Circuit-Breakers for High Pressure and Large Power.

E. W. RICE.

(Amer. Inst. Elect. Engin., Trans., vol. xviii., December, 1901, pp. 895–908.)

The Author discusses the general considerations which should determine the design of large high-pressure electric-power stations, with special reference to the switchboard arrangements, and the best form of circuit-breakers. At the recent experiments at Kalmazoo the circuit-breaker designed by the Author for the Manhattan Railway Power Station never failed to open 1,200 kilowatt circuits and 1,300-kilowatt circuits up to 40,000 volts, the highest pressure employed, without sign of fire or smoke, and quite noiselessly, and the Author infers that they might be safely employed for much larger powers and pressures. Long break open-air switches are quite unsuitable, as even where sufficient room is available, they produce dangerously high resonance effects. At 40,000 volts, a circuit-breaker of this kind gave rise to an arc which held and flared to a length of over 30 feet, when it struck the line and short-circuited the system, producing at the same time high-voltage oscillations of two or three times the normal pressure. Another form of oil switch had evidently reached the limit of its capacity at 40,000 volts, flashing and, in some cases, smoking. Expulsion-tube air-switches operated up to 25,000 volts, but failed at 40,000 volts.

G. W. DE T.

Electric Cranes at Middlesbrough Docks.

(Electrician, vol. xlviii., 7 February, pp. 606–609; and February 21, 1902, pp. 688–689.)

Three 10-ton and seventeen 3-ton jib-cranes have been erected, together with twenty-four 1-ton capstans. In the 3-ton cranes the height of jib-top from the quay-level is 60 feet, the radius of jib is 44 feet 9 inches, the speed of lifting 3 tons is 150 feet per minute, speed of lifting $1\frac{1}{2}$ tons is 250 feet per minute, the revolving speed at the hook is 400 feet, and the travelling speed 30 feet per minute. Details of construction are described in the first article. The controller is a combination of two controllers, which are actuated by one lever. One controller actuates the lifting motion, and the other the slewing motion. The lever which controls them is so arranged that when moved in a vertical plane it actuates the lifting, and in a horizontal plane the slewing controller. The capstans are capable of hauling loads of 100 tons along a level road. Upon the motor shaft there is fixed an automatic mechanical brake, which locks itself if the capstan tends to run backwards through being overloaded. Tests were made on

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the 3-ton cranes, and it was found that a complete cycle of operations required 0·17 unit of energy. The operations included lifting 3 tons through 30 feet, slewing through 120°, lowering 3 tons 30 feet, hoisting unloaded hook, slewing back through 120°, and lowering hook to ground. This cycle of operations can quite easily be performed forty-five times in an hour, and with a practised driver a still higher rate of speed is possible.

W. H. S.

Standardising Electrical Machinery. G. KAPP.

(Inst. Mech. Engin., Proc., vol. iv., pp. 825–840; discussion, September, 1901, pp. 841–845. Paper read before Glasgow Engineering Congress (Section III) 1901.)

In this Paper the Author deals with the standards for rating and testing electrical machinery provisionally adopted by the German Association of Electrical Engineers in June, 1901, a complete translation of the regulation being given as an Appendix to the Paper. They deal with generators, motors, rotary converters, motor generators, and static transformers. For rating purposes a division is made into three classes, according to the time during which they are to be used, viz., (*a*) intermittent use; (*b*) short-time use; (*c*) continuous use. Class (*a*) includes motors for cranes, hoists, traction, etc.; class (*b*) those in which the period of work is shorter than necessary to reach the final temperature, and the period of rest is long enough to permit the temperature to fall approximately to that of the air. The rated power is to be that which can be given off (*a*) for one hour without exceeding the temperature limits; (*b*) for a number of hours stated in a plate attached to the machine; (*c*) continuously. In the latter case the temperature rise is measured after a ten hours' run in the case of moving machinery, and whenever it has reached a stationary value in the case of transformers. The temperature limits, in ordinary cases, and if the air-temperature does not exceed 35°, of insulated conductors, commutators, and slip-rings, are, for cotton-covered wire 50°, for paper-covered wire 60°, and for wires insulated with mica, asbestos, etc., 80°, an additional 20° being allowed in each case for tramway motors. With regard to overload, it is pointed out that this should only occur for a short time, and under such temperature conditions that the permissible temperature rise is not exceeded, and, with this limitation, it is provided that generators, motors, and converters must be capable of an overload of 25 per cent. for half an hour, on the condition that, in the case of alternators, the power factor should not be lower than that marked on the plate; while motors, converters, and transformers must be capable of an overload of 40 per cent. during 3 minutes, on the condition that, for motors, the normal terminal pressure is to be maintained. The measurement of insulation resistance is not prescribed, but a breakdown test at high voltage, and this has

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been designedly kept within reasonable limits, since a breakdown test at very high voltage may, even if the machine stands it, cause permanent injury.

The most difficult task of the committee was the framing of rules for testing efficiency, and this has been met by giving eight methods, and leaving to the maker the right of selecting the one to be used, which is to be specified in his tender.

In the course of the discussion, P. E. Huber observed that his experience indicated that a test of 8 hours to 10 hours was not always conclusive for machines having to stand continuous work under full load (*e.g.*, for electro-chemical purposes), perhaps for months. Such machines sometimes showed their defects only after 2 days' or 3 days' continuous working. The Author, in the course of his reply, referred to the important point raised by Huber as one that might be reconsidered. A 10 hours' test might or might not be enough for big machines, depending on their construction.

G. W. DE T.

St. Paul and Minneapolis Interurban Railway.

(Street Railway Journal, vol. xix., March, 1902, pp. 159–170.)

This Paper deals mainly with the causes which have made such a great financial success of this line. Great stress is laid on the high character of the track construction. Of the 251 miles of track, 76 miles have cast-welded joints. 25 miles on paved streets have 80-lb. T-rails, 7 inches high, laid without ties, with a concrete beam 15 inches wide by 8½ inches deep under each rail. The track is held to gauge by tie-rods 10 feet apart. The flange-way for the wheels is made with granite block toothing in asphalt streets, and brick in brick-paved streets. In unpaved streets the standard construction is an 80-lb. T-rail, A.S.C.E. standard, as used on steam-roads. Most of the rest of the track consists of 56-lb. and 60-lb. rail. The power-supply from the St. Anthony Falls water-power plant has had to be supplemented by the aid of the old steam plant to supply the peaks of the load. This plant is not capable of being worked under economical conditions, and the increase in traffic has now made it inadequate. A three-phase steam plant, generating at 3,450 volts, is therefore being erected alongside the water-power plant, which can be operated in parallel with the latter, allowing the water-wheels to run with a constant full load, and making the steam-engines do the greater part of the regulation. A 3,500-kilowatt three-phase General Electric generator is to be used, direct-connected to a vertical Reynolds-Corliss-engine by the Allis-Chalmers Company. It is of the revolving field fly-wheel type, and the specifications require that it should operate for 24 hours at the rated load with not more than 30° C. rise above the engine-room temperature, and that at the close of such a test it shall stand a 50 per cent. overload for

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one hour without more than 42·5° C. rise, the construction being such that with an engine-room temperature of 25° C. the insulation will not be injured by the specified rise. The engine is to be compound condensing, with 46-inch and 94-inch cylinders respectively, with a 60-inch stroke, running at 75 revolutions per minute. The building will be laid out to contain six of these units, with the capability of indefinite extension. Six Babcock and Wilcox boilers are on order, with coils for superheating, it being intended to superheat to 120° C. Each boiler has 5,500 square feet of heating surface, and is normally rated at about 550 HP.

G. W. DE T.

The Great Northern and City Electric Railway.

(Street Railway Journal, vol. xix., March, 1902, pp. 200–207.)

This article contains a very full description of the tube-construction work for this railway, with illustrations, including drawings showing details of one of the Greathead shields designed for this work by E. W. Moir, a director of the firm of S. Pearson and Sons, the contractors. A brief description is also given of the power-station and of the electric plant to be installed. The line is about 6,200 yards in length, mostly tunnel. The tube is 16 feet in diameter, except at Moorgate Station, where it is increased to 23 feet. A novelty in construction, introduced after the commencement of the work, consists in making the upper half only of the tube of the ordinary cast-iron segments, the lower half being constructed of Brindle brickwork 15 inches thick, of bricks capable of sustaining a pressure of 400 tons per square foot. A cast-iron bearer plate is placed on the line of contact between the cast-iron segments and the brickwork, so as to distribute the pressure equally over the latter. All the machinery required in the construction has been run by means of 20-HP. Westinghouse 4-pole motors driving a line shaft to which the various machines were belted. The motors were run upon loose pulleys, and put on to the shafting as required. The electric power was obtained from the local supply companies.

G. W. DE T.

Fly-wheels for Low-Speed Engines for Electric Lighting and Traction. A. M. DOWNIE.

(Inst. Engineering and Shipbuilders, Trans., vol. xlv., November, pp. 24–88; discussion, December, 1901, pp. 35–67.)

The Author explains fly-wheel functions, and gives three Figs. of crank-effort diagrams with a brief explanation thereof, and the following formula for determining the weight of the fly-wheel to

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fulfil certain conditions: If E be the total energy stored in a fly-wheel of weight w (supposed to be concentrated at the radius of gyration), when moving with a mean peripheral velocity of v_0 feet per second; Δ_E the fluctuation of fly-wheel energy stored in the fly-wheel when changing from the minimum velocity v_1 through v_0 to the maximum v_2; w the work done by the engine in one revolution; q the coefficient of speed variation allowable between the maximum and minimum limits; k the coefficient of fluctuation of energy.

$$q = \frac{v_2 - v_1}{v_0} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$E = \frac{w v_o^2}{2g} . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$\Delta_E = \frac{w}{2g}(v^2_2 - v^2_1) = \frac{w}{2g}(v_2 + v_1)(v_2 - v_1);$$

or
$$\frac{w}{g} \cdot v_0 (v_2 - v_1) = 2Eq \quad . \quad . \quad . \quad . \quad (3)$$

But
$$\frac{\Delta_E}{w} = k, \text{ and therefore } k = \frac{2Eq}{w}.$$

Also
$$2E = \frac{kw}{q}, \text{ and } \frac{w}{g} = \frac{kw}{qv_o^2} \quad . \quad . \quad . \quad . \quad (4)$$

The mass of the fly-wheel is directly proportional to the coefficient of fluctuation of energy and the HP., and inversely proportional to the coefficient of variation of velocity and the square of the speed. The majority of fly-wheels are of cast iron with a maximum peripheral velocity of about 100 feet per second, or about 80 feet to 90 feet per second on the mean circumference, the maximum stress due to centrifugal force being about 1,000 lbs. per square inch.

For lighting loads, q varies from 1/100 to 1/200.
For lighting alternators in parallel, q varies from 1/200 to 1/300.
For traction, q varies from 1/200 to 1/500.
For traction American practice, q varies from 1/450 to 1/650.

q is sometimes expressed in "Electrical degrees" of variation per impulse:—

Let p = pairs of poles of generator. The number of degrees described by each pair of poles per revolution = 360. The number of degrees described by one engine impulse = $p \times 360$/number of engine impulses per revolution. If ϕ is put for the permissible total variation in degrees then the ratio $S = \phi \times$ number of engine impulses per revolution $\times\ p/360$, which should correspond with q as given above. A common value for ϕ is 6°, a 3° increase or lag

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from the mean. The coefficient of fluctuation of energy is the most important factor in fly-wheel design, and for this purpose crank-effort diagrams must be constructed. Tables are given with values of k and q, and fluctuation of crank effort. Actual design and construction are considered. A discussion followed the reading of the Paper.

J. T. R.

The Automobile and Specialty Co.'s Flash Boiler.

(Automobile Review, vol. vi., March, 1902, pp. 49–50.)

The boiler is built up of a number of sections which are connected together side by side. Eight of these are employed for a light car of the runabout type. The sections are made of a special steel, having a tensile strength of 70,000 lbs. per square inch. They resemble hollow drums, 9 inches in diameter and 3 inches across, and are provided externally with vertical ribs which increase their heating surface. Central openings in each end serve to connect them in series with one another and to connect the boiler both with the water-feed and with the steam-supply pipe. Steel disks are provided inside the sections; these are centrally placed, and are half an inch smaller in diameter than the cavities in the drums. The disks compel the water and steam to pass over a greater surface in the generator, and the space between the disk and the section itself is filled with small particles of copper. The sections are connected together by heavy nipples, and the boiler is placed horizontally over the heating burner. An automatic feed-water system is used. A pump driven by the engine delivers water from the supply-tank into a closed seamless drawn-steel tank, communicating with the one end of the boiler. This latter tank, which is fitted with a pressure gauge, contains air acting as a compressible cushion. The water is free to flow to the generator or to return from it to the tank; the feed to the boiler therefore depends upon the relative pressure in the tank and in the boiler. The pressure in the tank is kept constant by the combined action of the pump and of a relief-valve in its delivery pipe; the relief-valve opens when the pressure rises abnormally, and it returns the surplus water to the supply-tank. The fuel feed to the burner is also automatic. The fuel is taken to the burner through a specially-constructed copper plug, which is screwed into one section of the boiler. The plug is so arranged that it produces an excess of gas if it is overheated, and the gas thus formed is said to retard the flow of fuel to the plug, reducing the fire.

A. G. N.

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Superheated Steam in Engines. R. Lenke.

(Inst. Mech. Engin., Proc., vol. iv., pp. 847–853; discussion, September, 1901, pp. 854–864. Paper read before the Glasgow Engineering Congress (Section III.) 1901.)

The behaviour of superheated steam is similar to that of gases. The thermal capacity of steam is 0·48, therefore little heat is required to superheat it. The heat radiation loss due to working with superheated steam is less than that with saturated steam owing to the lower calorific value of superheat as compared with the latent heat of saturated steam. Superheat increases the volume per unit of weight as shown by Table I.:—

Table I.

Pressure.	390° F.	570° F.	750° F.
70	1·1	1·33	1·57
115	1·06	1·29	1·52
170	1·02	1·24	1·46

Owing to increase in volume, superheated steam requires less B.T.U. to produce a given volume than saturated steam at the same pressure. Table II. gives total heat per cubic foot for various pressures:—

Table II.

Pressure.	Saturated.	390° F.	570° F.	750° F.
70	233	219	192	175
115	350	337	297	267
170	492	485	432	398

For example, to produce 1 cubic foot at 115 lbs. and a temperature of 570° F. (350 − 297)/350 = 15 per cent. less heat is required than to produce 1 cubic foot of saturated steam at the same pressure. To obtain full economical benefit the highest temperature safe for superheater and engine is 660° F. to 700° F., but engines must be specially designed to stand this temperature. The Author mentions various parts of engines likely to give trouble with superheat. J. T. R.

Kennicott Water-Softener.

(Railroad Gazette, vol. xxxiv., March 14, 1902, p. 181.)

As installed on the Union Pacific Railroad, this apparatus has a capacity of 150,000 gallons per day, and consists of a settling tank, which is a steel cylinder 43 feet high and 13 feet in diameter, alongside of which is a lime-water tank 25 feet long and

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3 feet diameter. The water comes from two artesian wells about 1,000 feet deep, and is led to the softener through a 6-inch supply-pipe. The treated water is drawn off into two 50,000-gallon storage tanks placed about 400 feet apart. The following analysis shows the water before and after treatment:—

	Grains per Gallon.	
	Before Treatment.	After Treatment.
Silicia	0·79	0·40
Carbonate of lime	9·86	3·45
Carbonate of magnesia	3·51	0·20
Sulphate of magnesia	7·03	None
Carbonate of soda	1·12	0·29
Sulphate of soda	4·70	7·80
Chloride of soda	16·48	14·49
Total solids	43·49	26·63
Incrusting solids	21·19	4·05

The steel settling-tank has a conical bottom, and from the point where the water enters above there is an inner cone-shaped partition, the diameter increasing downwards. The water flows downwards inside the cone, and ascends between the conical partition and the outer shell to the soft-water overflow. This increases the cross-section and gradually diminishes the rate of flow in both directions, favouring the deposition of solids. The cone also serves as an oil-trap when condensing-water is used. Floats and valves regulate the process automatically. For treating 150,000 gallons in 24 hours, 57 lbs. soda ash and 1½ barrels of lime are required on the Union Pacific.

F. J. R.

Overman Steam-Car.

(Scientific American, vol. lxxxvi., 1 March, 1902, p. 139.)

This is a light two-seated vehicle, built on the lines now common to American vehicles of this class, but with various modifications in details. The mechanism is as far as is possible enclosed. An automatic feed-regulator controlled by a thermostat is employed, the feed-pump being driven at a comparatively low speed from the rear axle; the stroke of the pump-plunger is adjustable. The feed-water is heated by passing through a coil of tubing in an exhaust steam-jacket. An injector is also fitted. Air-pressure in the fuel-tank is maintained by a steam-operated pump under control of the driver. This pump is also automatically controlled by a pressure diaphragm, which brings the pump into action if the pressure in the fuel-tank falls 4 lbs. below the normal. The boiler is fitted with a fusible plug, the melting of which

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causes a valve controlling the gasoline supply to close. The boiler is of the vertical fire-tube type, and the engine a two-cylinder vertical, with cylinders 2·5 inches bore × 3 inches stroke. Transmission is by a single-chain gear to the live rear axle.

C. R. D'E.

Consumption Trials of Motor-Carriages.

(Génié Civil, vol. xl., 22 March, 1902, pp. 349–350.)

Tables of results of several recent consumption trials held in France are given. Table I. contains the results obtained in the French Automobile Club trials of petrol cars during the Paris Exhibition of 1900 :—

TABLE I.

	Total Weight Loaded.	Total Consumption.		Consumption per Tonne-Kilometre.	
		800 Kilometres of Road.	34·35 Kilometres of Level Track.	Road.	Track.
	Kilograms.	Litres.	Litres.	Litres.	Litres.
Voiturettes—					
Gladiator	400	48·500	2·250	0·129	0·150
de Dion-Bouton . .	560	64·000	3·090	0·139	0·158
Renault Frères . .	490	66·000	2·750	0·172	0·159
Voiturettes (weight from 400 to 1,000 kilograms)—					
Peugeot	750	56·680 pr. 687 km.	3·100	0·110	0·120
Delahaye	689	55·900 pr. 682 km.	2·850	0·120	0·122
Light cars (weight from 1,000 to 1,500 kilograms)—					
Delahaye	1,320	64·750 pr. 680 km.	3·680	0·072	0·081
Gobron-Brillié . .	1,230	73·000 pr. 619 km.	5·000	0·095	0·118
Rochet-Petit . . .	1,000	71·000 pr. 690 km.	3·000	0·102	0·687
Carriages (weight from 1,500 to 2,000 kilograms)—					
Delahaye	1,420	97·000 pr. 697 km.	4·000	0·077	0·080
Brouhot	1,760	142·000 pr. 687 km.	5·000	0·117	0·080
Carriages (weight more than 2,000 kilograms)—					
Panhard-Levassor .	4,310	241·500 pr. 697 km.	3·900 pr. 11 km.	0·081	0·078

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Table II. gives the best results for the "*Criterium de l'alcool*," of 28 October, 1900, organised by the "Vélo" from Paris to Rouen, 127 kilometres.

TABLE II.

	Total Weight Loaded.	Total Consumption.	
		For 127 Kilometres.	Per Tonne-Kilometre.
Light cars—	Kilograms.	Litres.	Litres.
Darracq	540	8·500	0·123
Clément-Panhard	567	9·000	0·124
Carriages—			
Gobron-Brillié	1,279	15·000	0·092
De Diétrich	1,540	19·400	0·099
Panhard-Levassor	1,280	17·000	0·104

Table III. gives the best results for the "*Course Paris-Roubaix*," 7–8 April, 1901, 278·64 kilometres.

TABLE III.

	Total Weight Loaded.	Consumption 50 per Cent. Alcohol.	
		For 278·64 Kilometres.	Per Tonne-Kilometre.
Voiturettes—	Kilograms.	Litres.	Litres.
Darracq	570	18·00	0·1120
Light cars—		. .	
Gillet-Forest	725	22·850	0·1120
Darracq	725	23·300	0·1140
Carriages—			
Société Nancéenne	1,325	33·000	0·0890
Panhard-Levassor	1,550	39·450	0·0909
Delahaye	925	24·000	0·0920
Delahaye	1,240	34·000	0·0979
Martha-Bollée	1,535	42·500	0·0988

Table IV. gives the best results for the "*Criterium de Consommation*," organised by the "Auto-Vélo" on 5 February,

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1902, and also over the same course on 5 March, 1902, distance 100 kilometres.

TABLE IV.

——	Total Weight.	Fuel employed 5 March and its Density.	Consumption 5 March.			Consumption 5 February per Tonne-Kilometre.
			Total per 100 Kilometres.	Per Tonne-Kilometre.		
	Kilogr.		Litres.	Litres.	Kilogr.	Litres.
Voiturettes—						
Peugeot . . .	550	Essence 690	4·890	0·0889	0·0613	0·1050
Peugeot . . .	550	Id.	4·900	0·0891	0·0614	0·1060
G. Richard . .	510	Essence 712	5·580	0·1090	0·0776	0·1140
Light cars—						
Darracq . . .	750	Essence 716	4·850	0·0646	0·0462	0·0876
De Dion Bouton .	865	Essence 690	6·330	0·0731	0·0504	0·0894
Korn	733	Id.	5·500	0·0750	0·0517	0·0911
G. Richard . .	600	*Alcohol* 50%	4·985	0·0830	„	0·1027
Peugeot . . .	1,060	Essence 500	8·890	0·0838	0·0586	0·0888
Carriages—						
Chenard et Walker	1,070	Essence 714	5·500	0·0514	0·0367	0·0599
Bardon . . .	918	Essence 705	6·470	0·0704	0·0496	0·0857
Heavy carriages—						
Delahaye . . .	2,060	Essence 690	15·130	0·0734	0·0506	0·0943
G. Richard . .	1,240	Essence 680	10·000	0·0806	0·0548	0·1085
Delahaye . . .	1,240	Essence 690	10·650	0·0858	0·0592	0·1076
Industrial cars—			Per 60 km.			
De Diétrich . .	2,890	Essence 698	12·900	0·0744	0·0519	0·0709
Gillet-Forest . .	1,838	Essence 716	13·290	0·1208	0·0865	0·0966

The most striking results obtained on 5 March being the consumption of 0·0514 litre per tonne-kilometre for the Chenard and Walker car, and 0·0646 litre for the Darracq light car. The Chenard-Walker car ran on a mixture of petrol and petroleum of specific gravity 0·714, and the Darracq on petrol of specific gravity 0·716 + a solution of picric acid dissolved in alcohol.

C. R. D'E.

Locating Metals by Electricity.

(West. Electn., vol. xxix., 16 November, 1901, pp. 317–318.)

Describes a method of locating metallic veins underground, which consists in carrying an overground wire across the land to be surveyed, in a series of parallel lines. At the end of each line contacts are inserted, and the resistance between them is measured.

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It is stated that the fall of resistance, when near a metallic vein running between the contacts, is so great that no difficulty is found in locating a metallic vein. It is stated that an average resistance of 54,000 ohms fell in a particular case to 56 ohms when over a rich copper vein. Other instances are given.

LL. B. A.

Efficiencies of Electric Cranes. R. MATTHEWS.

(Mech. Eng., vol. ix., 15 March, 1902, pp. 348–350. Paper read before the Manchester Association of Engineers.)

This Paper gives several Tables showing the results of tests made on cranes of various powers in operation at Armstrong's works. These tests were carried out under ordinary conditions, and the figures are the results of a number of trials for each load. Figures relating to the size and construction of the different cranes are also given. With a three-motor 70-ton crane the highest efficiency was reached when hoisting a load of 20 tons at the rate of 3·75 feet per minute, and was calculated to be 62·8 per cent. With a load of 80 tons the efficiency was 50 per cent., the lifting being done at the rate of 2·56 feet per minute. With a four-motor 50-ton crane an efficiency of 61 per cent. was shown with a load of 21 tons lifted at the rate of 4·5 feet per minute, the efficiency at full load being about 45 per cent. An old 40-ton crane driven by an elaborate system of ropes, belts, spur-wheels, etc., the whole being worked by a motor, showed at best an efficiency of 16·7 per cent. Other cranes were also tested, and full figures are given in each case, both for hoisting, traversing, and travelling.

W. H. S.

Electric Percussion Rock Drills.

(Engineering News, vol. xlvi., 29 August, 1901, pp. 130–131.)

The Paper prescribes three types of percussion drills driven by electric motor. The Durkee electric drill has an independent motor of 1½ HP. driving through a flexible shaft. The motion is given by a special crank which gives a slow return and quick forward or cutting stroke, the driving collar moves the drill spindle through springs so as to cushion the motion if the drill is not striking the rock, and to allow for irregularities in the feed. The drill is rotated by the usual rifled rod and pawl. The machine makes 580 strokes per minute, and weighs 230 lbs. without tripod.

The Gardner drill is very similar. Instead of a crank a cam is used, so that the forward stroke takes one-quarter of a revolution, the backward one-half, and the remaining quarter it is stationary. The

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drill is made in two sizes, with motors of 1½ HP. and 2 HP., weighing 150 lbs. and 200 lbs. The smaller gives 600 blows with 2½ inches stroke, the larger 500 blows of 3 inches stroke per minute. A special feature is a slipping friction clutch, to avoid blowing the motor fuse if the drill jams in the hole.

The Hercules drill endeavours to copy the method of hand-drilling. The drill and motor in one frame are carried on a stand. The drill does not oscillate, but is slowly rotated by a rifled bar, being struck at the back by a motor-actuated hammer giving 700 blows per minute. The weight complete with stand is 400 lbs. LL. B. A.

Power Transmission from St. Moritz to Lausanne on the Constant Current System. E. BIGNAMI.

(Elettricità, Milan, vol. xxi., 16 March, 1902, p. 164.)

The town of Lausanne acquired in 1898 a water-power of 10,000 HP. to 15,000 HP. on the Rodano at St. Moritz, 56 kilometres distant from Lausanne. A committee of five experts examined the tenders sent in for different systems, and selected the Thury system of constant continuous current at 23,000 volts. The amount of the tender was 7,365,000 francs, while that of the three-phase system was 8,005,000 francs. The present installation provides for 5,000 HP. The generating station contains five turbines by Escher-Wyss, each developing 1,000 HP. at 800 revolutions per minute under a head of 32 metres. Each drives directly two dynamos, each of which gives 150 amperes at 2,300 volts. The five pairs of dynamos are connected in series and give 23,000 volts. There is no switchboard, but each set is provided with a cast-iron column on which are mounted a short-circuiting switch and an ammeter. A set is put into circuit by opening the turbine regulator till the dynamos give 150 amperes, when the short-circuiting switch is opened. The line, 54 kilowatts long, consists of two bare copper cables of 150 square millimetres section, run on insulators. The Lausanne station at Pierre de Plan contains at present five motors of 400 HP. each at 2,150 volts. Each motor has a small switchboard containing a voltmeter, an ammeter, and two short-circuiting switches, one automatic and the other operated by hand. Each motor also has an automatic regulator which shunts the field and shifts the brushes. Four of the motors drive three-phase generators supplying current at 300 volts for light and power in Lausanne. The fifth motor drives a continuous-current dynamo for the tramways, for which is installed a battery of accumulators and a booster. Plant for transmitting a further power of 5,000 HP. will shortly be installed. G. H. B.

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Rhyl Electricity Works.

(Elect. Engin., vol. xxix., 28 March, 1902, pp. 438–443.)

This station is worked in connection with a dust destructor. There are two Babcock boilers, each giving 5,000 lbs. of steam per hour, and also two smaller ones, each evaporating 2,000 lbs. of water per hour; the latter can either be fired by coal or by means of the destructor gases. The destructor consists of four cells, each burning 10 tons a day. The small boilers are placed immediately above the destructors, by which they are fired, and the others are placed at the end of the destructor house away from the engine-room but near the chimney. The generating plant includes three 150-kilowatt six-pole machines giving 300 amperes at 500 volts. There is also a balancer-booster set and a motor-driven tramway booster, which can raise the pressure 100 volts, and has a capacity of 2½ kilowatts. The accumulators consist of 274 cells, having a capacity of 25 kilowatt for nine hours. The crane lifts 4 tons, and has a span of 30 feet 6 inches. The distributors have a section of 0·125 square inch, and the arc lamps are run ten in series on 500 volts.

W. H. S.

Grand Rapids, Holland and Lake Michigan Railway.

G. A. Damon and W. D. Ray.

(Street Railway Review, vol. xx., March, 1902, pp. 127–137. Paper read before the Chicago Electrical Association, 7 March, 1902.)

This line is 45 miles long, and runs for the most part through more or less open country. The power-house contains two 500-kilowatt three-phase alternators, and distribution is effected through rotary converters. The transmission wires are of aluminium, and carry current at 20,000 volts; the wires are placed 24 inches apart at the corners of an equilateral triangle. They are fixed to Provo glass insulators, weighing 6 lbs. each, with a diameter across the base of 7½ inches. Glass insulators are supposed to be better than porcelain, and cost less. They do not require to be tested, and the life without deterioration is said to be longer.

W. H. S.

The Vevey-Mont Pélérin Funicular Railway. H. Muraour.

(Elettricità, Milan, vol. xxi., 2 March, 1902, p. 132.)

The length of the line is 1,577 metres, and the height ascended 412 metres. The gradients vary from 15 per cent. to 54 per cent., and the sharpest curve has a radius of 274 metres. There are

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five stations on the route—Vevey, Corseaux, Beausile, Chardonne-Fougny, and Baumaroche—and these are arranged so that the ascending and descending cars stop simultaneously at two stations. The two cars are attached to a cable 1,600 metres long, passing over guide pulleys along the line, and over two pulleys in the station at the summit, one of which is the driving pulley. It is driven through gears and a belt by a motor of 80 HP. Current is supplied from a station at a small distance. In this two gas-engines of 25 HP. each, working with Dowson gas, drive a dynamo giving current at 250 volts. A battery of accumulators of 400 ampere-hours' capacity is connected across the line, and is charged by the motor acting as a generator when either car is descending the gradient of 54 per cent. There are various safety devices at the station and on the cars. On the shaft of the driving pulleys is a band brake, which acts automatically if the speed is too high and cuts off the current. On the cars are two automatic brakes which grip the rails; a third brake is operated by hand, and, in case of the cable breaking, the axles in rotating close up the bearings by an endless screw gear. An overhead line enables the conductor to signal to the station to stop the motor.

G. H. B.

Electric Mining Installation in the Riebeck Mines.

E. Beutom.

(Écl. Électr., vol. xxix., 21 December, 1901, pp. 428–430.)

This installation, executed by the A. E. G., of Berlin, has some novel features. The motive power consists of two Korting four-cylinder Korting gas-engines of 125 HP. each, actuated by gas distilled from coal, which is treated to a dry heat for the production of paraffin. This gas has a calorific power of 1,800 calories per centimetre compared to 5,500 calories per centimetre for oil gas. The transmission is at 3,000 volts, and the motors work at 500 volts, transformers being used. The most novel feature is a hoist used for carrying workpeople into the pits. It is driven by a three-phase induction motor, and has a special regulating apparatus, with three brushes working on a series of contacts arranged like a commutator, by which it may be started, stopped, and reversed. A friction brake is provided, but in ordinary work the braking is effected by running the motor as a generator returning current to the line. The description is illustrated with photo blocks of the plant.

Ll. B A.

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Electric Street Railways in Chicago. E. B. Ellicott.

(Western Electrician, vol. xxx., 1 March, 1902, pp. 141-142.)

This is a report by the city electrician to the authorities, who instructed him to consider the "physical condition" of the important street railways in Chicago. He reports that the Union Traction Company has 600 miles of track; but the use of a small trolley wire and an inadequate system of connecting the feeders to the trolley are undesirable features. The safe carrying capacity of the trolley wire is 140 amperes; feeders are connected to it every 200 feet in congested districts, and every 800 feet in outlying districts. But in congested parts the overhead wire has not a sufficient capacity to furnish the amount of current required to work the cars at a proper speed. On a certain section of the line which appears to be near the centre of the town, the transmission losses are estimated at 33 per cent., but a large percentage of this is probably lost in the return circuits, which are said to be insufficient and composed of poorly-bonded rails. The motors are geared for a maximum speed of 15 miles per hour, but during the busy hours the maximum speed is about 11 miles an hour, and in the congested district the power is insufficient to propel a loaded car at a greater speed than 6 miles an hour. The Chicago City Railway Company has 200 miles of track, and uses a large-sized trolley wire. But they, too, have a district which is seriously congested, and where the cars are only worked at 4 miles an hour. On this section during busy hours the transmission losses are estimated at 50 per cent. The steam plant of this company is said to be very much out of date, and with the use of better machinery the Author estimates that a saving of 33 per cent. could be effected in the coal consumption. He also considers that the times occupied in getting the cars up to full speed and in stopping them are unnecessarily long, and though this may contribute to the consumption of a smaller amount of power, this probably contributes to accentuating the congested state of the traffic.

W. H. S.

Permanent Way.

(Railroad Gazette, vol. xxxiv., March 21, pp. 203–205; and with discussion, March, 28, 1902, pp. 220–223. Extracts from the Report of the Committee of the American Railway Engineering and Maintenance-of-Way Association.)

Track.—The Committee, in its report, considers the following subdivisions of its subject: Maintenance of line; maintenance of surface; maintenance of gauge; inspection of track and track tools. They are all discussed in detail. In considering the object of the super-elevation of the outer rail in curves, the

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Committee recommend for ordinary practice, as giving the essentially correct theoretical elevations, the formula $E = \frac{G V^2}{32 \cdot 16 R}$, where E = elevation in feet, G = standard gauge, V = velocity in feet, R = radius of curve in feet. Since the elevation required is a function of and depends upon the train speed, speed is the first element to be determined. It is not unsafe to run over a curve at a higher speed than that for which it is elevated; a train may safely run 10 miles per hour over a curve which has no elevation, or 60 miles per hour over a curve elevated for 50 miles per hour; but the practice is not recommended. The Committee advocated originally for ordinary practice a maximum elevation of 7 inches, although on the subject being thoroughly discussed a difference in elevation of 8 inches was finally recommended. The above formula gives results expressed in the following Table:—

VELOCITY IN MILES PER HOUR.

DEG.	10	15	20	25	30	35	40	45	50	55	60	65	70	DEG.
1	1/16	1/8	1/4	3/8	5/8	13/16	1	1 3/8	1 5/8	2	2 3/8	2 3/4	3 1/4	1
2	1/8	5/16	1/2	5/8	1 1/16	1 5/8	2 1/8	2 5/8	3 1/4	4	4 3/4	5 1/2	6 1/2	2
3	1/4	1/2	3/4	1 1/4	1 3/4	2 3/8	3 1/8	4	4 7/8	6	7 1/8	8 3/8	..	3
4	1/4	5/8	1 1/16	1 5/8	2 3/8	3 1/4	4 1/4	5 3/8	6 5/8	8	..	..	..	4
5	3/8	3/4	1 5/16	2 1/16	3	4	5 1/4	6 3/8	8 1/4	..	..	..	..	5
6	7/16	15/16	1 5/8	2 1/2	3 9/16	4 7/8	6 5/16	8	..	..	..	..	..	6
7	1/2	1 1/16	1 7/8	2 7/8	4 1/8	5 5/8	7 3/8	..	..	..	..	..	..	7
8	9/16	1 1/4	2 1/8	3 5/16	4 3/4	6 1/2	8 3/8	..	..	..	..	..	..	8
9	5/8	1 3/8	2 3/8	3 3/4	5 3/8	7 1/4	..	..	..	..	..	..	..	9
10	11/16	1 1/2	2 5/8	4 1/8	5 15/16	8 1/16	..	..	..	..	..	..	..	10
11	3/4	1 11/16	2 7/8	4 1/2	6 1/2	8 7/8	..	..	..	..	..	..	..	11
12	7/8	1 7/8	3 1/8	5	7 1/8	..	..	..	..	..	..	..	..	12
13	7/8	2	3 7/16	5 3/8	7 3/4	..	..	..	..	..	..	..	..	13
14	1	2 1/8	3 11/16	5 3/4	8 3/8	..	..	..	..	..	..	..	..	14
15	1 1/16	2 5/16	3 15/16	6 1/8	8 7/8	..	..	..	..	..	..	..	..	15
16	1 1/8	2 7/16	4 1/4	6 5/8	..	..	..	..	..	..	..	..	..	16
17	1 1/4	2 5/8	4 1/2	7	..	..	..	..	..	..	..	..	..	17
18	1 1/4	2 3/4	4 3/4	7 1/8	..	..	..	..	..	..	..	..	..	18
19	1 3/8	2 7/8	5	7 5/8	..	..	..	..	..	..	..	..	..	19
20	1 3/8	3 1/16	5 1/4	8 1/4	..	..	..	..	..	..	..	..	..	20

Finally the Committee, although recognising a departure from theoretically correct principles, advised that the lower rail should not be depressed.

Ballasting.—The Committee state that the materials which best fulfil the requirements for ballasting are broken stone, gravel, coarse sand, burnt clay, partially disintegrated rock, slag, and cinders, and various products resulting from the separation of ores. Recommendations for depth of ballast give a minimum of 8 inches, with an average of 12 inches. Minimum dimensions for cross-sections are assigned to rock ballast, and maximum to light materials, such as coarse sand, in which the sleepers or ties should be buried. Burnt clay formed a leading topic in the ensuing discussion, the trend of opinion being that it formed a good ballast when pure clay, free from sand or vegetable matter, was obtainable. One ton of coal produced from 4 yards to 4½ yards of good ballast.

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Supply and Life of Cross Ties.—American railroads have only recently commenced to treat their ties. In recommending trials, on a small scale, of the various timber preserving processes, the Committee draws special attention to the cheaper varieties of petroleum, which, although not an antiseptic itself, may possibly be rendered so by the addition of other substances.

Rails.—This Committee confined their deliberations to the subjects of rail sections and specifications. It was urged that much better rails than are at present being made could be turned out from the steel now in use, provided it received the proper treatment in rolling. The bad effects arise from the use of a too high finishing temperature, which simply changes the form of the mass without changing its structure. A standard specification for steel rails was brought forward and recommended for adoption, the chief feature of which is the drop test. This is to be made on a piece of rail not more than 6 feet long, the test piece being taken from the top of the ingot and placed on solid supports 3 feet apart. The following impact tests to be made with a drop test machine having a tup of 2,000 lbs. weight, with an anvil block of at least 20,000 lbs. :—

Weight of rail per yard .	45–55	55–65	65–75	75–85	85–100 lbs.
Height of drop . . .	15	16	17	18	19 feet.

If any rail breaks when subjected to this test, two additional tests to be made with other rails from the same blow of steel, and if either of these fail all the rails of the blow to be rejected. The report also mentions that the Pennsylvania Railroad advocates higher carbon percentages than have been hitherto used, as the drop test shows that rails finished at a lower temperature give a greater deflection than those finished at the higher.

C. E. A.

Steam-Engine Governors and Parallel Running of Alternators. C. F. Guilbert.

(Soc. Int. Elect., Bull., vol. ii., April, 1902, pp. 281–327.)

This Paper is a *résumé* of the conclusions arrived at by a commission of inquiry appointed to discuss the whole question of the parallel running of alternators as affected by the engine governors (understanding by this term mechanical governors, those worked either wholly or in part by electrical means being outside the scope of the inquiry). Thirteen points were laid down for discussion, each of which is treated separately in this Paper. Taking them in order, these points, with the conclusions arrived at, are briefly as follows :—

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(1) The desirability of defining by a special coefficient $K = \frac{N_0 - N_{max}}{N_0 (N_0 \text{ and } N_{max})}$ = angular velocities at no load and full load respectively, the controlling power of the governor. This coefficient, or some other similar function of the speeds, has been called the coefficient of isochronism. Inasmuch, however, as isochronism is a most undesirable condition for parallel running, the term is inappropriate, and "governor coefficient" is proposed as a better name. The curve representing mean angular speeds as a function of the load is of great importance; this is really the mean between two nearly parallel curves, the difference of whose ordinates is called the stability; the actual mean speed for any load may oscillate between the two limits, this oscillation being due, amongst other things, to variations in friction and to play in bearings and gear-teeth. For a given load the "stability" of the governor ought, for reasons which are explained, to be greater than the difference between the maximum and minimum instantaneous speeds during one revolution. This point is discussed, and it is shown that, for the same stability, the loads taken by different sets (supposed of equal capacity) will tend towards equality as the curves referred to are more inclined towards the axis of load.

(2) and (3). Various engine-makers and central station engineers were asked to obtain experimentally curves of mean engine speed as a function of load, some of which are reproduced. Pressure in the steam chests, in one typical case, was maintained constant by means of the throttle valve; the curve is nearly a straight line, slightly convex to the origin. The drop is about 5 per cent. between no load and full, the load being that between the alternator terminals. If I.HP. is plotted as abscissa, the convexity is increased. It is desirable, but not absolutely necessary, that the drop in speed should be proportional to the load; the possible difference in the load taken by two identical sets in parallel is then constant for all loads. The form of curve giving a difference of load proportional to the load is that which is convex to the origin; curves with a point of inflexion and a tangent nearly horizontal are quite impossible for satisfactory parallel running.

(4) and (5). The necessity for a considerable "governor coefficient" for parallel working necessitates a special compensation arrangement to maintain the frequency constant. Three such devices are described. One consists of a weight movable either by hand or from the switchboard by means of a small electromotor, which varies the effort which the governor must exert in order to come into action; or the effect of the weight may be altered without the necessity for displacing it, by means of the current in a solenoid. The second way is to act on the admission valve of the engine so as to vary the pressure at the steam ports as the load varies. The third method is to use some automatic regulator, such as the Denis compensator, employed by

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some engine-builders in Paris. The two first methods, while giving the necessary variation of speed, are not always sufficient to maintain it constant; in such a case, a method devised by Picou has been used, by which a bye-pass with an easily regulated valve is used to shunt the steam admitted to a cylinder.

(6) *What is the best Type of Governor?*—Theoretically any form of governor can give a required percentage drop, but practical considerations of dimensions may make one system preferable to another. Quick-acting governors, in which centrifugal force is counterbalanced by springs, are best for parallel running; the possibility of modifying the range, &c., when in place is also an important consideration, and spring governors or those which make use of an inclined plane lend themselves easily to this.

(7) *Governor oscillations.*—The period of these ought not to coincide with the period of oscillation of the flywheel, if dangerous hunting is to be avoided. With spring governors the period is generally very short, and can easily be calculated.

(8) *Method of damping oscillations.*—Short-period oscillations, such as, *e.g.*, those depending solely on the governor, can be damped by a dashpot; the damping need not be considerable, as friction alone will do nearly all that is required. Long-period oscillations require very powerful damping; but here a curious effect comes in, that if the orifices in the dashpot piston are adjusted to give the best effect for oscillations of long period, the resulting damping for short-period oscillations will be exaggerated. A remedy for this is to have a dashpot provided with valves which relieve the pressure of the oil when this exceeds a certain limit.

(9) Governors ought to be of short-period of oscillation, and, to avoid resonance, the various oscillation periods of the plant ought to be different.

(10) *The influence of multiple expansion on governor oscillations.*—When, as is generally the case, the governor controls the admission to the high-pressure cylinder only, its rapidity of action is diminished by multiple expansion—a condition prejudicial to good parallel working; and the tendency to oscillations is also increased. When the governor acts on the different cylinders, this tendency is less marked.

(11) *Oscillations of long period.*—These are given rise to by variation in the existing torque under certain states of load and by somewhat undefined conditions of the governor, particularly excessive damping. In the case of two alternators in parallel, they can be produced by a want of balance of power between the two machines owing to lack of simultaneity in the action of the governors. Long-period oscillations can be reduced (1) by increasing the "governor coefficient," (2) by reducing the distance between the two limiting curves which represent mean speed as a function of load, and (3) by increasing the power of the governor. If the alternator drives the engine, however, these oscillations may reappear.

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(12) and (13) deal with the best way of governing several alternators running in parallel. Should each set have its own governor, as is the usual practice, or would it be better to regulate the speed of the whole system by a single governor (*a*) acting either on one only of the engines, the governors of the others only serving in case of accident, or (*b*) acting simultaneously on the admission of all the engines? The first method (each plant separately governed) demands that the governors should be very sensitive and should have practically the same percentage drop at full load; but in practice it is found possible even with different types of governor to obtain satisfactory results. The disadvantage of this method is that the load comes on or off all the machines simultaneously. Rateau proposes to use governors with large percentage drop in combination with Denis compensators; these would be adjusted for the different machines to speeds varying slightly the one from the other. Thus, in the case of four machines running at a speed of about 100 revolutions, the compensators might be set at 102, 101, 100, and 99 revolutions respectively. Thus there would never under normal conditions be more than one machine running at reduced load; the others would be either fully loaded, or would be taking no load and would of course then be shut down. The second solution (one governor controlling the whole of the alternators running in parallel by regulating the admission of its own engine) may do well enough where the variation is small, as on lighting circuits. Where, however, the variations might exceed the capacity of the controlling machine, serious dangers might be introduced. Against this there is the great advantage that all the other sets are acting under the best conditions economically. With asynchronous alternators this method would be the natural one to employ, if the control were effected by a synchronous alternator. The third method, while electrically leaving little to be desired, is mechanically very difficult to realise. [The memoirs or notes on which this report has been based are appended to the report. They are written by Blondel, Rateau, Miet, Guilbert, Van der Stegen, Picou, Vigreux and Brillié, and Chevrier, and the thirteen points enumerated in the report are discussed at some length.]

B. P. S.

Circulation in Water-Tube Boilers. W. H. Booth.

(Electrical Review, vol. l., 4 April, 1902, pp. 539–541.)

Taking as an example a small tube boiler with nearly vertical tubes averaging 5 feet in length, and 1¼ inches inside diameter, evaporating 600 lbs. of water per hour per square foot of grate area, or 13·33 lbs. per superficial foot of tube surface, this is practically equal to 26 lbs. of water per tube per hour, or 0·0072 lb. per second. The water contents of the tube being 2·6 lbs. or

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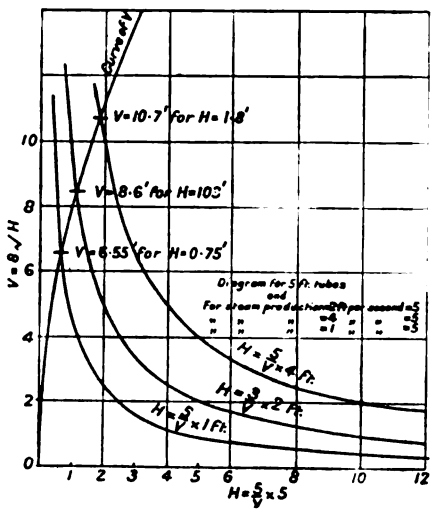
0·0426 cubic foot, the tube will be emptied of $\frac{1}{7\frac{1}{6}}$ of its contents, or one-sixth inch of its length per second. The volume of the steam formed at 200 lbs. pressure absolute will be 0·0163 cubic foot per second, occupying about 23 inches length of tube—so that nearly half the length of tube is filled with steam each second, and must be replaced with water. Moreover, the steam carries up the water in front of it into the steam space.

Taking V as the velocity of flow $= 8\sqrt{H}$; H being the head of water represented by the space occupied by the steam, which latter is represented by S, the Author constructs the accompanying



diagram, giving three curves for H representing the production of 1 foot, 2 feet, and 4 feet per second, length of steam-plugs in tube. The theoretical velocity of circulation for each case is given by the intersection of these curves with the curve of velocity. The diagram is for tubes of 5 feet in length, and the evaporation is stated in linear feet of tube occupied by steam per second.

The Author estimates the quantity of water, the flow of which should be provided for in such boilers, and shows that the down-comers usually provided are inadequate in area. For flatly-inclined or comparatively horizontal tube boilers with larger tubes the case is slightly different, but, taking the Belleville boiler, the Author shows the inherent defects in its design from this point of view of water circulation, and considers it "absolutely dangerous and unscientific unless provided with mechanically-propelled circulation so certain and positive as to compel a sufficiency of water to pass through the tubes," jointly and severally.

F. J. R.

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Producer-Gas and its Use in Engineering. F. J. Rowan.

(Institution of Engineers and Shipbuilders, Trans., vol. xlv., March, 1902, pp. 27–45.)

The Author avoids the usual confusion of applying names to the various gases by including them all under the term "producer," and points out that they vary comparatively little in composition. The objection against producers that heat is lost in combustion is founded on the false theory that all the carbon present is capable of yielding its full amount of heat when converted into CO_2. An example based on L. Bell's analysis is given to illustrate this. In order to utilise the heat derived from cooling the gas, a chemical reaction with steam is brought about, ½ lb. of steam per lb. of coal being the average quantity required. Producers are divided into two classes: (1) Those which send the blast among the fuel in a lateral direction, such as Dowson, Mond, Wilson, &c.; (2) those which introduce the blast vertically, such as the Duff. The blowing area in a Duff grate is given as 1,720 square inches as against 160 square inches in a similar Wilson producer, thus ensuring a high degree of combustion. Various bases of efficiency are touched upon. The Duff producer shows an efficiency of 81 per cent. on D. Clerk's basis,[1] which states that with pure carbon and air alone a perfect producer would give a mixture of 1 volume CO and 2 volumes N, leaving at a high temperature. After emphasising the wastefulness of the ordinary furnace, the Author considers various applications of producer gas. (1) In steel making, iron puddling, welding, and processes requiring a high temperature, producer gas has won its greatest triumphs. Drawings of suitable producers are given. (2) For re-heating iron, forging, &c., the Weardale furnace is very suitable, 1¾ cwt. to 2¼ cwt. of coal being required per ton of iron heated. In (3) a usual form of foundry stove is illustrated, and (4) deals with gas-fired boilers, an average of 9·29 lbs. of water evaporated per lb. of coal being obtained. (5) and (6) describe the application of gas to brick-kilns and gas-retorts. Under the heading Power the following figures occur: "The heating power of producer gas is within the range 144 B.Th.U. to 190 B.Th.U. per cubic foot," and "the cost of production, using expensive coal, is about 1*d.* per 1,000 cubic feet, and using slack, about ½*d.*"

Discussion.—P. N. Cunningham had used the commonest dross with good results. C. G. Norris gave the following figures for heating plates:—

	Ordinary Coal-Fired Furnace.	Weardale Gas-Fired Furnace.
Size of furnace	15 feet 6 inches by 6 feet 10 inches.	14 feet 10 inches by 5 feet 6 inches.
Lot of plates heated 53 hours	17 tons.	45 tons.
Cost of heating per ton of plates	4*s.* 5*d.*	2*s.* 2*d.*

[1] Minutes of Proceedings Inst. C.E., vol. lxxxiv. p. 79.

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J. F. Maclaren had been using anthracite and coke for producers, and experienced trouble with clinker, and with tar clogging the gas-engine valves. A. Wilson considered coke from the south easier to deal with on account of its higher quality. Clinkering was increased if the gas had to be transmitted to a distance necessitating higher pressure. Producers could be shut down for a day or so. The President described an automatic gas-producing regulator. Such regulation is much easier with coke than with bituminous coal. The Author, in reply, explained the relation between the heat valves of C and CO. The advent of possible coal famines put producers in a more favourable position than formerly. He did not understand Maclaren's trouble with tar. J. F. Maclaren explained that he had used Scotch anthracite, and had found that tar arising from coke was worse than that from anthracite.

R. C. R.

Insulation of Electric Supply Cables. P. CHARPENTIER.

(Soc. Int. Élect., Bull., vol. ii., March, 1902, pp. 204–234.)

The high-insulation resistance usually required of cable-makers is not in itself of much value; even if the resistance were reduced to one-thousandth of its usual value, the loss of energy by leakage would be negligible. These high insulations are demanded merely as a guarantee of the quality of the cable, but they should not enter into the specification of a cable, for an insulation of equal durability and equal strength against rupture might have far less resistance and be equally serviceable in practice. The insulation of a cable should satisfy the three conditions of (1) a definite maximum leakage, (2) strength against rupture, and (3) durability. As a measure of the resistance should be taken that observed when the current has become practically constant, not that after one minute's electrification. The ratio of these two resistances varies largely in different sizes of cables, and for continuous currents the former only has any practical value. The strength against rupture bears very little relation to the insulation resistance. It depends really on the uniformity of the materials used and the care exercised in manufacture, for over a small service, the thickness of insulation for a given strength is often only about one-tenth that required in a long cable. It is not advisable to test the whole cable, as is usually done, at a pressure double the working pressure, as such a test may permanently injure the insulation. The better test is to measure the pressure of rupture over a length of the cable and allow a factor of safety of 4 to 5. The Author suggests that cables could be cheapened by substituting for the armouring, lead sheathing, and for a dielectric of high-insulation resistance, a thick layer of moderately insulating material sufficiently strong to withstand handling and laying, which could be applied to the bare copper as the cable was laid.

G. H. B.

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Electric Pumping Plant.

(The Engineer, vol. xciii., 11 April, 1902, pp. 355.)

This plant, which is said to be the largest of its kind in this country, has been put down by Scott and Mountain at the Eldon Colliery, Durham. The generating plant consists of a 220-kilowatt steam-driven dynamo, supplying current at 500 volts to motors at the bottom of a shaft, 150 yards deep. The motors drive the pumps by cotton ropes; the motor speed is 450 revolutions per minute; the pump speed 27 revolutions per minute, and each pump delivers 500 gallons per minute against a head of about 400 feet. On test the following figures were obtained on full load. The pumps delivered 64·8 gallons of water against a head of 400 feet per lb. of coal used in the boilers. The ratio between the output at the dynamo terminals and the HP. in the water pumped, the pumps being at a distance of 1,000 yards from the generator, was 72·7 per cent. The efficiency of the pumps alone was found to be 85 per cent., and of the motors 91 per cent.

W. H. S.

Electricity Supply Tariffs. A. Wright.

(Inst. Elect. Engin. Journ., vol. xxxi., pp. 444-486. Discussion, March, 1902, pp. 486–531.)

The costs of supplying electricity may be divided into preparation and production costs. Preparation costs consist of —(1) Interest on the preliminary expenses; (2) annual cost of plant and maintenance of it, or the standing-by costs; (3) service costs. The production cost is defined as the increment of expenditure incurred by making a given plant supply an extra unit of electricity. The Author gives methods of separating these two costs from the monthly returns of the station, and shows that the production costs are small compared with the preparation costs. Another item of cost is the loss made in supplying a certain class of consumer. The best method of apportioning the standing-by charges to different consumers is by the indications of sluggish maximum demand indicators. An allowance, however, must be made for the fact that all consumers do not make their maximum demand at the same time. A fair allowance for this general diversity in the use of the plant is best made by dividing the annual standing-by costs per kilowatt demanded, by the ratio of the total of the consumers' individual demands in kilowatts during the month of maximum load, to the maximum load of that month, and debiting each kilowatt demanded by the consumer at this new rate. The Author recommends that an annual load-curve should be drawn for the station, by adding together the number of hours during which any given load has been supplied during the year,

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and plotting a curve between the percentage of annual maximum load and hours per annum. From this curve can be ascertained: the load-factor at which any proportion of the plant has been used; the ratio of the production and preparation costs at any load; the total cost of production at any load; the number of units sold at any load; the maximum losses economically allowable in the feeders; and what proportion of the plant should be equipped with condensers, economizers and other coal-saving apparatus. Examples of this curve are given for Brighton and Stepney, from which is prepared an analysis of the costs in the Brighton station, and a statement showing the sources of profit and loss. From the latter it appears that against 2,331 consumers who bring in a profit of £4,370, there are 524 who cause a loss of £1,855. Curves are given for Brighton and Nottingham showing the cost of supply to consumers having different load-factors. From these curves the best tariff can be seen. In Brighton this would be 12*d.* for the first 200 hours per annum and $\frac{3}{4}d.$ afterwards; in Nottingham it would be 8*d.* for the first 264 hours and $\frac{3}{4}d.$ afterwards. The greater part of the units sold are consumed by the class of small householders, and by shops, with the use of their lamps of 3 to 4 hours per day, and it is their interests which have to be specially consulted in fixing on a tariff. Large consumers should not be encouraged by a system of discounts, as they are often a source of loss. The Author then discusses various systems of charging, and points out their defects, and concludes by giving formulas for calculating the basis of charging on the maximum demand system. Discussion: R. A. Dawbarn pointed out that the use of maximum demand indicators entails considerable expense in first cost and in maintenance; that a flat rate is fairly applicable to 90 per cent. of the consumers, and that it is not worth while incurring the expense of giving every consumer an indicator to accommodate a small percentage of consumers. W. H. Patchell said that in districts where there is competition the maximum demand system is at a disadvantage, as consumers prefer a flat rate that is fixed to a system on which they do not know at what rate they will have to pay. W. M. Mordey referred to the difficulty in getting consumers to understand the system. He questioned the soundness of the principle; churches, for instance, are penalised by it, but when a church has a heavy load, the load on the houses of those attending the church is correspondingly diminished, so that the church cannot be said to increase the station load. The cost of the indicators in small installations is an important item, and the loss of pressure in them has also to be considered. He gives a table showing that the average load-factor of stations supplying on a flat rate is higher than that of stations using the maximum demand system. J. R. Dick referred to the adoption of Wright's system on the Continent and in America. He mentioned the case of a power company in Silesia, where the supply is made at cost price, and a charge made per kilowatt demanded. He deprecates the custom of offering supply at a flat rate or on the demand system at the option

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of the consumer. L. Andrews pointed out the difficulties that may arise from the irregularity of quarterly accounts made out under the demand system. He does not advise that it should be forced on consumers, but prefers to change a flat rate, and give long-hour consumers the option of reducing their bills by adopting the demand system. R. H. Smith traced out the four stages through which the system has passed. First, there was the Hopkinson scale of an annual charge per lamp, plus a charge per unit; second, the Wright plan of a charge per watt of annual maximum actual consumption; third, the plan of basing the charge on the quarterly instead of the annual consumption; fourth, the application of the diversity factor. Each change has been in the direction of flattening the scale. With the larger introduction of motors the scale will be still further flattened, and perhaps so much as to bring the Wright system down to the old flat rate system.

G. H. B.

Electricity Supply in Bulk. H. A. Earle.

(Inst. Elect. Engin. Journ., vol. xxxi., pp. 884–903; discussion, April, 1902, pp. 903–923.)

In the light of the experience gained at power-stations abroad the schemes of the English power companies cannot, in the Author's opinion, be regarded as speculative ventures. The opposition which the promoters of the English schemes had to meet when obtaining parliamentary sanction was based, partly on the objections raised by local authorities, and partly on unfounded fears that the schemes would prove financial failures.

In order to show the fallacies underlying opposition of the latter class, the Author has submitted to a detailed examination the prospects of the Yorkshire Electric Power Company's scheme for supplying the West Riding of Yorkshire with electricity in bulk. Within the area covered by the powers granted to this company there is a population of 2,500,000, and 1,000,000 of this total are outside the present area of supply by the eleven towns which have built and are now operating electric supply stations. It is also estimated that within the area covered by the company's Bill there are 27,000 factories and workshops, utilizing 2,000,000 HP. The present scheme of the Yorkshire Electric Power Company is to erect four generating stations of 25,000 HP. each. In view of the above figures, there should be little difficulty in finding the requisite number of power users to keep these stations running at their maximum capacity.

The Author passes on to an examination of the Yorkshire scheme under the following heads:—Board of Trade regulations. General system. Cost of generating stations. Cost of trunk mains. Cost of sub-stations. Cost of distributing and service mains. Total expenditure and capital account. Works cost per

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unit generated, including management. Trunk mains, upkeep and superintendence. Expenditure at sub-stations and upkeep. Distributing and service mains, upkeep and superintendence. Summary of expenditure per annum. Analysis of total units sold per annum. Total cost per unit sold. Rates of charge. Financial results.

The total capital expenditure upon the four generating stations, mains, transformers, etc., is estimated to amount to £2,666,666.

The running costs and total annual expenditure are calculated for an output of 140,000,000 units, with the following results:—

	Pence per Unit.	Total.
		£
Cost of coal	0·128	74,666
Oil, waste, water, and stores	0·04	23,400
Wages and station staff	0·052	30,000
Repairs and maintenance	0·05	29,167
Rent, rates, and taxes	0·05	29,167
Management, Directors' Fees, Salaries of chief and assistant engineer, office salaries, legal expenses, insurance, etc.	0·025	15,000
Sinking fund on four generating stations at £330,000 each —£1,320,000 at 3 per cent.	0·068	39,600
	0·413	241,000

The total annual expenditure being:—

	£
Annual expenditure at four generating stations, including office expenses, etc.	241,000
Trunk mains	16,750
Sub-stations	35,250
Distributing and service mains	24,750
Annual expenditure	317,750

The financial results show a profit of £248,250, as indicated in the statement given below:—

	£
The total units per annum sold equal	123,700,000
Which, at a charge of 1·1*d.* per unit, yields a gross revenue of	567,000
The annual expenditure is	317,750
Leaving a profit of	248,250

And this is equal to—

	£
4½ per cent. on £666,666 debentures	30,000
and 10·9 per cent. on £2,000,000 share capital	218,250
	248,250

J. B. C. K.

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New Generating Station at Rochester, N.Y.

(Power, N.Y., vol. xxii., February, 1902, pp. 1–6; and Electrical Review, N.Y., vol. xl., 1 February, 1902, pp. 146–152.)

The old plant has been replaced by a combined steam and water plant. The generating apparatus consists of six 1,360-kilowatt, 2,500-volt, 60 ∾, 2-phase, 90 revolutions per minute steam-sets, and three 350-kilowatt, 2,500, 6 ∾, 2-phase, waterwheel sets. The former are of the revolving field type. Two separate steam-driven, 75-kilowatt exciters are provided. The engine-room has mezzanine floors, carrying the various steam-pipes, etc., and is on a lower level than the boiler-house. The Babcock and Wilcox boilers are fed by Acme stokers. The boilers are each rated at 650 HP., and have a heating surface of 6,500 square feet. Arrangements have been made for the future use of superheaters. The engines are of the vertical cross-compound type, by the Southwark Foundry and Machine Company, Philadelphia. The normal steam pressure is 160 lbs., and the consumption 13·5 lbs. per I.HP.-hour. The internal variation of speed is $\frac{1}{4}$ of one geometrical degree from the mean. The governor controls both high- and low-pressure cylinders, and is of the Porter type. The King synchronising device is employed. Single throw-oil switches are used. The instruments include polyphase wattmeters and power factor indicators. The cables are of the paper, lead-covered, duplex type, drawn into tile ducts. The sub-stations are equipped with synchronous-motor-generator sets of 500 kilowatts and 75 kilowatts. The low-tension cables are of the concentric paper type. The installation of such a high proportion of steam plant where water-power is available is justified by the promoters on the grounds that water-power is fitful and uncertain, and has to be utilized, in this case, at several points; and that with cheap prices the fuel is but a small proportion of the cost of production.

E. H. C.-H.

Westinghouse Magnetic Brake for Tramcars.

(Mechanical Engineer, vol. ix., 10 May, 1902, pp. 626–628.)

The brake consists of a horseshoe magnet, suspended by spiral springs from the car frame, the two poles hanging down directly over the rail. The short-circuited motor current is passed round the exciting coil of the magnet, the result being that the poles are drawn downwards by the steel rail. The poles are fitted with soft iron shoes, which grip the rail, the whole forming a kind of slipper brake. The poles are also connected by levers which apply a brake to the wheel rims. Various forms of braking action are therefore applied at the same time by moving the handle of the controller beyond the "off" position in the opposite direction to that which starts the car.

W. H. S.

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Railway Signalling.

(Engineering, vol. lxxiii., 7 February, 1902, p. 184.)

An invention of J. Netter and H. Queyroul consists of a thin copper wire held between two arms over the engine cab. The wire is broken on coming into contact with a rod extended from the line signal. This opens an electric circuit, and works a signal disc and alarm-bell inside the cab, thus apprising the driver of "danger." For running through tunnels and under low-arched bridges the arrangement is automatically lowered and then raised again, as follows:—Two metallic brushes are fixed under the engine, and old rails are placed between the track rails, one in front and one behind the tunnel or arch, in such a position that one brush is earthed on one side, and the other on the other side, of the place where the bow has to be lowered and again raised. By means of a small 20-volt and 12-ampere-hour accumulator on the engine, an electro-magnet is caused, when one brush is to earth, to pull down the bow by moving an iron core, and when the other brush is earthed, a second electro-magnet operates in the same fashion to restore the bow to normal position. While it is down, an alarm-bell is kept ringing. Drawings of the apparatus are given. It has been tested on express trains running at maximum speed, and has worked satisfactorily. The broken wire is easily replaced while the train is running.

E. O. W.

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TO THE

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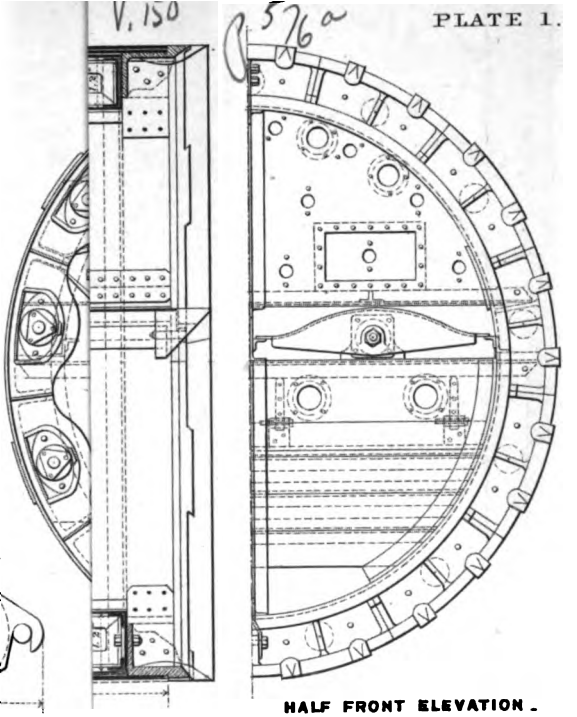

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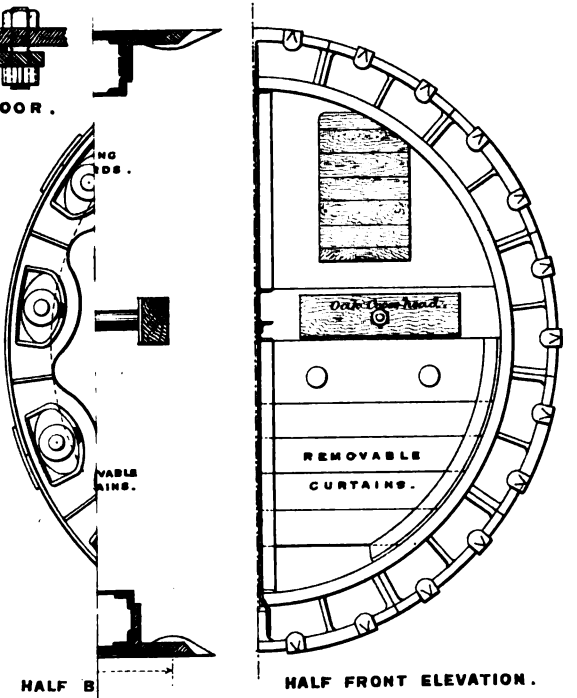

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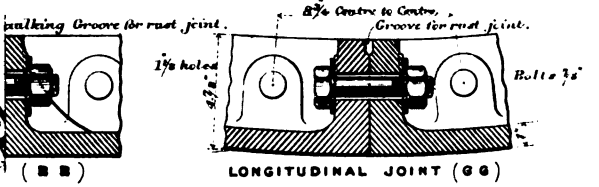

GINAL IRON LINING.

TUNNEL.

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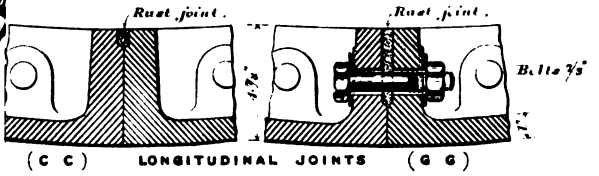

VISED IRON LINING.

TUNNEL.

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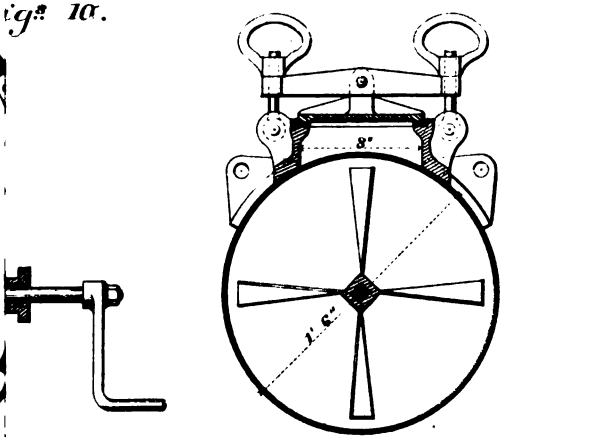
Figs. 10.



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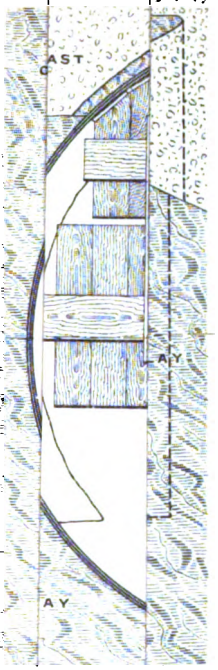

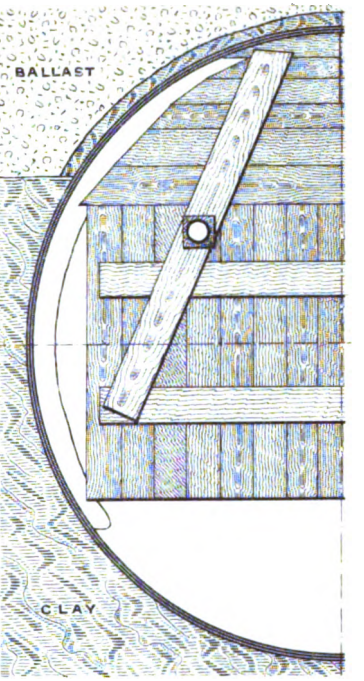

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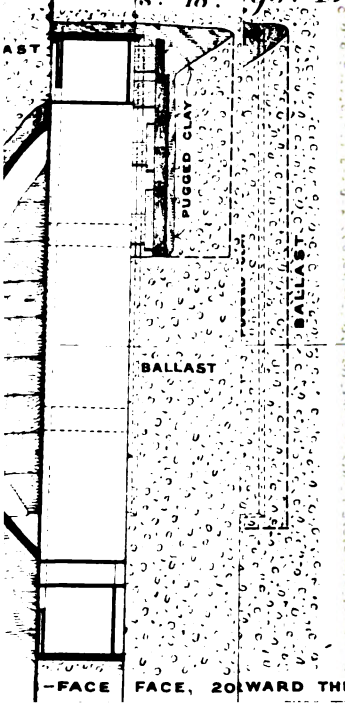
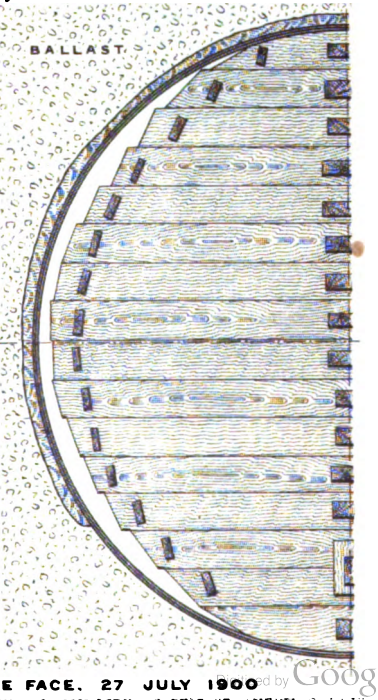
Figs. 18. & 19.





—FACE FACE, 20 WARD THE FACE. 27 JULY 1900

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Fig. 19.

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Fig. 23.

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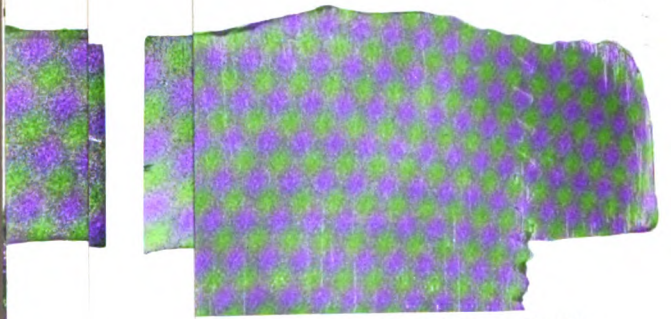
Fig. 41.



I COPPER FIRE-BOX AFTER 7 YEARS' SERVICE.

Fig. 42.

COPPER FIRE-BOX AFTER 12 YEARS' SERVICE.

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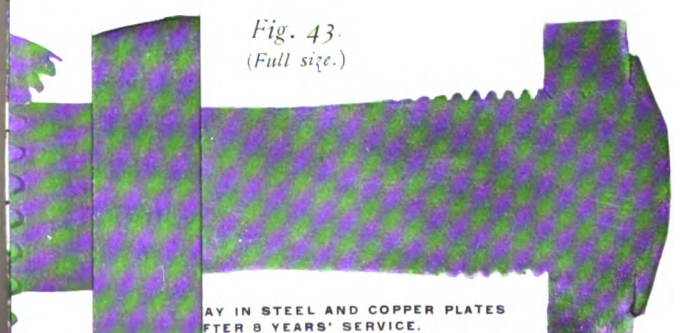
Fig. 43.
(Full size.)



AY IN STEEL AND COPPER PLATES
FTER 8 YEARS' SERVICE.

STEEL PLATE.

PPER-ZINC S

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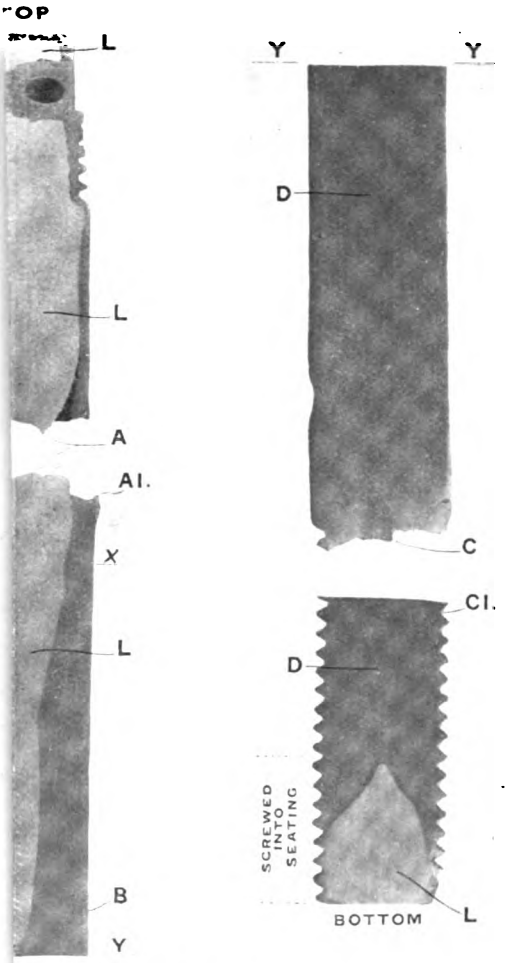
TAGE OF A MUNTZ-METAL STUD.

Fig. 44.—(Full size.)



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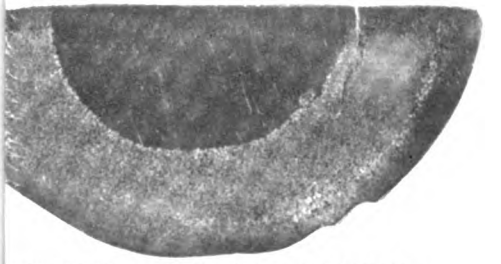

ROSS SECTION AT XX. MAGNIFIED 4 DIAMETERS.

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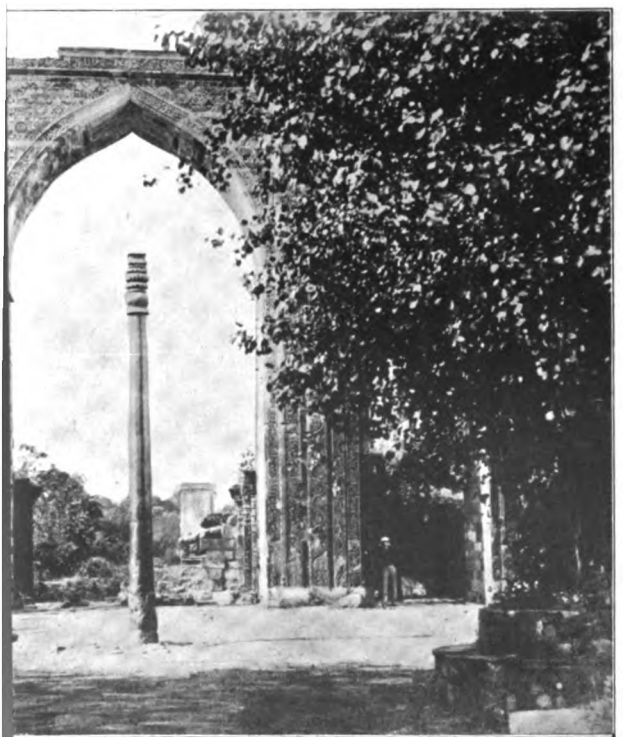

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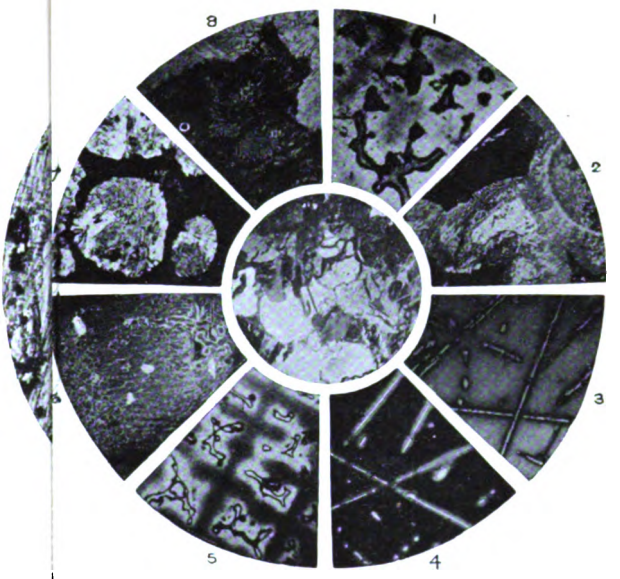

NOTE.

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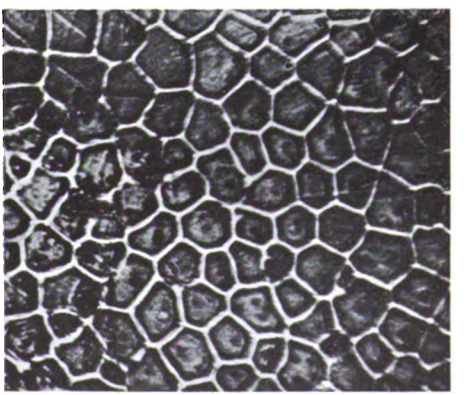

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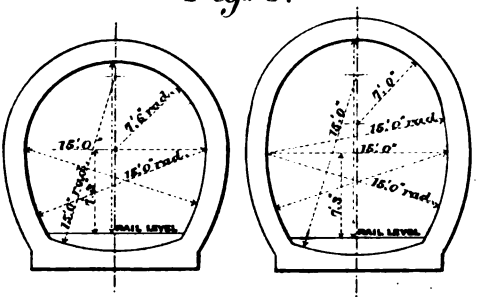

CROSS SECTIONS OF TUNNELS.

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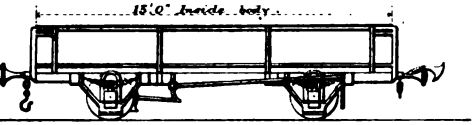
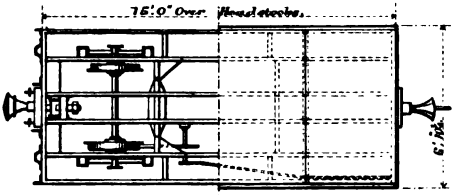


7-TON LOW-SIDED STEEL WAGON.



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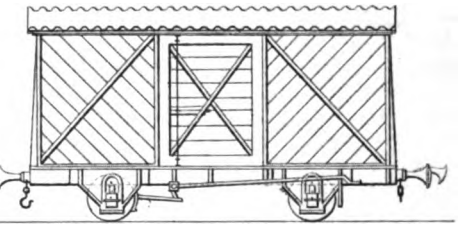

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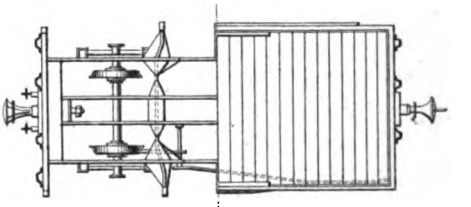

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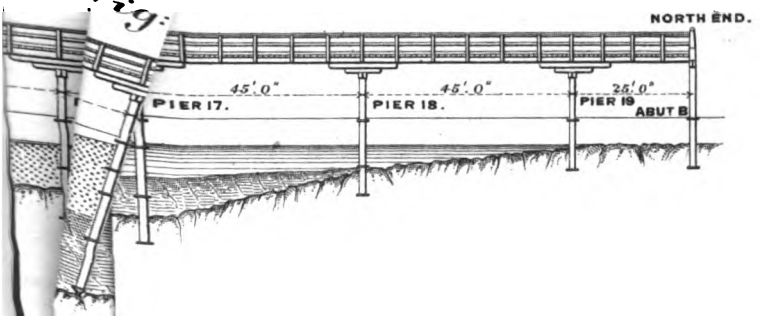

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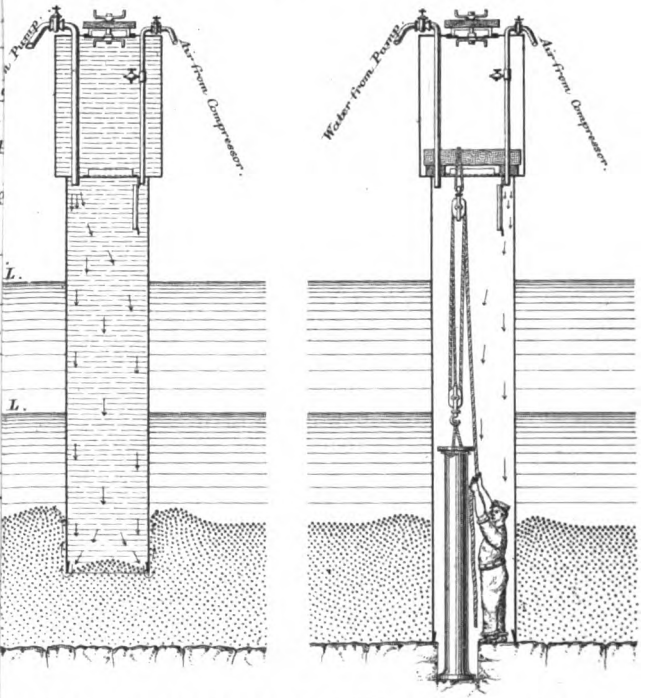

SECURING COLUMNS IN ROCK UNDERLYING SAND.

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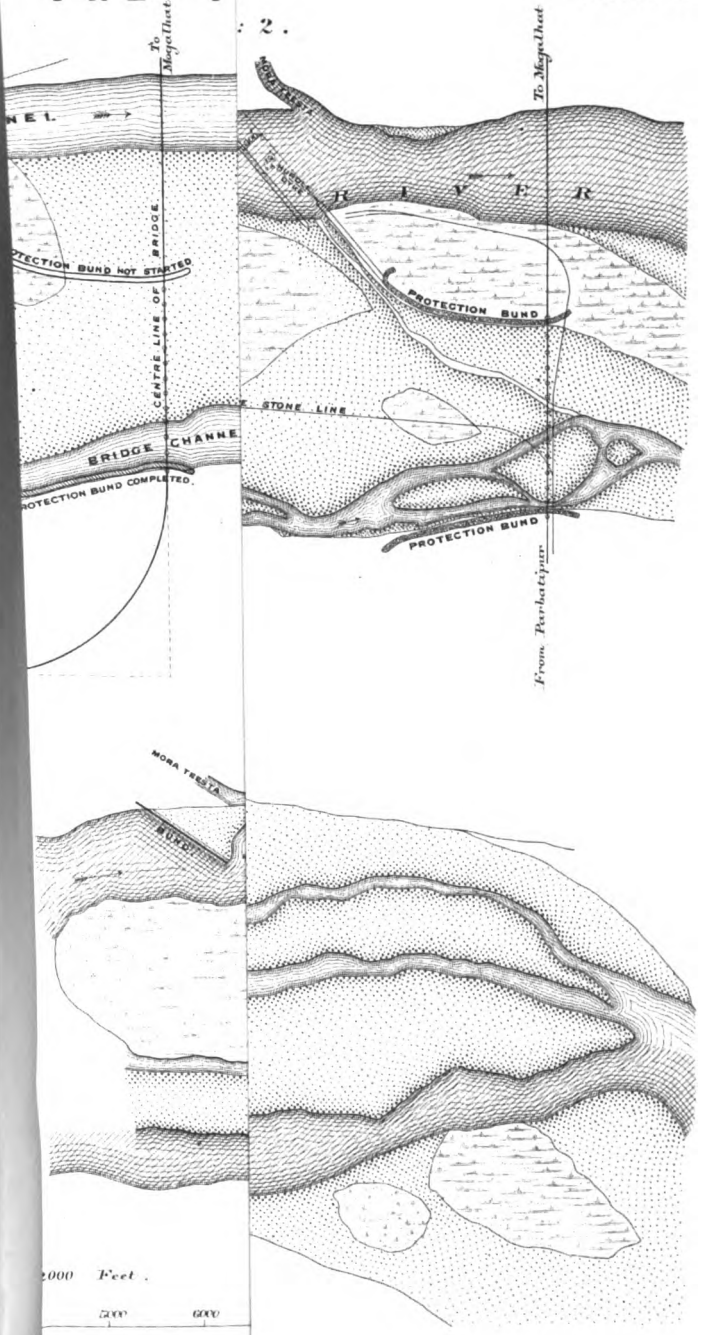

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